POWER PLANT ENGINEERING

GENERATION - TRANSMISSION - DISTRIBUTION - UTILIZATION

Contents

Instrumentation	2
With the Editors More Business in Business. Yearly Index. Modernization vs. Rehabilitation.	3
The Purpose of Instruments in the Power Plant	4
Instruments and Measurement	8
Pressure Measuring Instruments	13
Temperature Measuring Instruments	17
Quantity Measurements of Solids and Fluids	20
Tachometers for Speed Measurements	25
Boiler Room Instruments for Better Operation	27
Special Instruments for Improving Performance	31
Recording and Integrating Mechanisms	36
Electrical Instruments	39
Power and Energy Measurements	48
Resistance Measurements	52
Measurement of Power Factor, Frequency and Synchronism	54
Plant Operating Instrument Equipment	58
Instruments for Testing Power Plant Equipment	68
A.S.M.E. Holds Fifty-fifth Annual Meeting	74
Power Show Exhibits Indicate Trends in Perfection of Details	80
News from the Field	85
Acknowledgment	85
Power Plant Construction News	86

Contents of back issues of Power Plant Engineering will be found in Industrial Arts Index on file in Public Libraries.

NRA MEMBER U.S. WE DO OUR PART

JANUARY 1935

Vol. XXXIX., No. 1

Published on the first of each month, copyright 1935 by the
Technical Publishing Co., 53 W. Jackson Blvd., Chicago.
New York Office, 171 Madison Ave.

EDITORIAL STAFF: ARTHUR L. RICE, Editor. R. E. TURNER, Managing Editor.
A. W. KRAMER, RICHARD H. MORRIS, Associate Editors.

Subscription price. U. S. A. $2.00 a year; other countries, $3.50 a year. Single copy current issue, 25c; other countries, 35c. January 1 issue, U. S. A., 50c; other countries, 60c. Back issues, single copy, U. S. A., 40c; other countries, 50c. January 1 issue, U. S. A., 75c; other countries, 85c.

Member, Associated Business Papers, Audit Bureau of Circulations.
Circulation of this issue, 20,600

Machine for testing the efficiency of turbine nozzles and blading at the Westinghouse turbine laboratories.

INSTRUMENTATION

FEW factors are of greater importance in modern industry than those which involve the exact measurement and control of physical, chemical and electrical processes. Today, instruments are the most vital part of the equipment of our industry—without them, it would be blind and helpless as a ship at sea without compass or sextant.

Not only in the operation of machines do instruments exercise their ceaseless vigilance but in the design and manufacture of the machines themselves, instruments are involved in every step of the process. The photograph above, shows a typical instance. This shows a new testing machine for testing the balance and efficiency of turbine blades during operation in the Westinghouse turbine laboratories. It is a marvelously sensitive machine, and indicates blade balance or unbalance under varying speed conditions with an accuracy undreamed of by early turbine designers. Years ago in turbine manufacture, a simple static balance test was about all that could be applied. Today, with instruments such as those, every blade characteristic can be studied and measured and corrected. This is merely a typical example of modern instrumentation—there are countless others in every line of endeavor.

WITH THE EDITORS

More Business in Business

MANY AMERICANS have expressed the opinion that there is too much Government interference with private business. The Administration's claim is that business does not act for the greatest good of the greatest number of citizens and cannot or will not put its own house in order. May it be possible that private business is too much influenced by what Government is doing?

Every citizen should form intelligent opinions on matters of national policy and should certainly express his opinions through the voting privilege at every possible opportunity. But the main thought and effort of the individual needs to be concentrated intensely on the making and executing of aggressive plans for increasing his own activity. The great majority of us would be doing nicely if there could be just a moderate increase in business volume. This increase in business volume must come from the combined and cumulative effect of our millions of people each earnestly pushing his own job steadily ahead.

It is no good for Americans to sit around at the bottom of the hill gossiping about the mistakes of the Administration. We can not hitch-hike an easy ride to the top nor can we hope to fly up by clutching the pin feathers of the Blue Eagle. Every man of any experience knows that the industrial and economic life of America is far too vast and complicated for any government even to begin to regulate for any extended period. Government can not do the job for us and the mistakes of the Administration can not, in the long run, wreck the process of our recovery if the American people set out to accomplish that recovery.

Too much, has holding back been due to a self fostered feeling of uncertainty.

For instance, we often hear a manufacturer say, "I know my boilers are in bad shape and I could reduce my steam cost by replacing them with new ones of a more efficient type but I'm waiting until I find out what is going to happen."

So he runs his worn out equipment and waits.

Now whatever comes, his reserve fund, which must be in cash or bonds of some nature, will then be no more value than now in the purchase of boilers he needs so badly. His waiting will have done him no good but simply delayed the time when he gets his plant into sound, efficient operating condition. Very likely waiting will also have allowed his competitor to get the jump on him. By delaying sound rehabilitation measures the manufacturer loses, no matter what happens.

Let us hope that America will snap out of her woolgathering pre-occupation, put her plants in first class shape and get down to business right now.

Modernization vs. Rehabilitation

SEVERAL ROADS are open to the engineer desirous of building up the efficiency of his power plant to a modern standard, some of these may be merely expedients good for a short time only, while others have a more lasting value. The proper course is not always easy to determine, too frequently the temptation to save money on investment is likely to lead to an uneconomical expedient.

Among the most prominent defects of old power plants are worn or corroded equipment, obsolete equipment, inadequate auxiliaries and instruments, and obsolete heat cycles. The time comes in the life of all equipment when costs for repairs and replacements required to bring it nearly back to its original efficiency mount to nearly the price of new equipment, capable of higher efficiency. When this occurs with the major equipment of the plant a more intensive study of the plant should be made than that necessary merely to replace the unit. Auxiliary equipment such as pumps, fans, heaters, traps, control devices, may usually be replaced, or added to the present, without much question as to the economic results. If, however, the question of replacing steam generators or prime movers comes up for solution the whole question of modernizing the heat cycle along with the equipment should receive most careful study.

During the past 15 yr. high steam pressures, the regenerative cycle and binary vapor cycles have been brought to an economical place in commercial practice and offer possibilities in many plants now in need of modernization.

Just how these modern practices can be used in old plants is an individual problem, but their possibilities should be familiar to every engineer confronted with a modernization program. Superimposing high pressure boilers on a low pressure plant has been done in a number of instances with entire success. The mercury vapor cycle has established its claim to economical application in industrial as well as central station practice. Bleeding turbines for process steam and feedwater heating are well established practices but little used in old plants.

Industrial plants, particularly, have opportunities that were not open to them a decade ago due to advances made in the processes using the power plant services.

An old saying used in the study of mathematics, "let us get back to fundamentals", seems to apply equally well in the problem of power plant modernization, with emphasis, however, on the fact that fundamentals not only in the design but the services of power plants have changed quite radically.

Yearly Index

INDEX for Volume XXXVIII of Power Plant Engineering is now prepared and will be sent free to subscribers upon request.

The Purpose of

INSTRUMENTS *in*

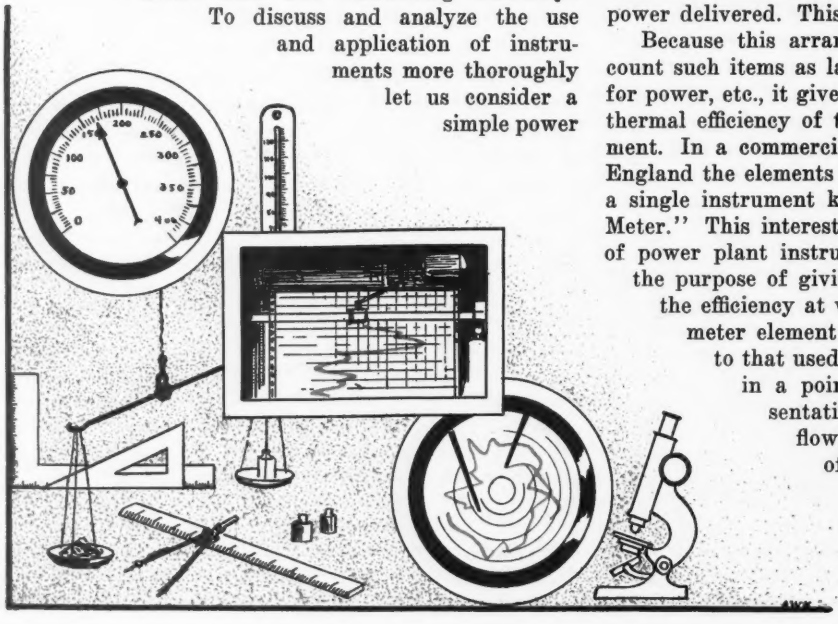
Primary considerations regarding the use and application of Instruments in the Power Plant. Why Instruments are needed, their purpose, their function, the factors which enter into their selection. Classification of measurements.

INSTRUMENTS PROVIDE US with information which is not directly obtainable by means of our senses. Our sense of feeling for example, except in extreme cases, enables us to distinguish between cold and warm but if we want to know the temperature with any degree of accuracy a thermometer is necessary. The primary function, then, of an instrument is *measurement*. Instruments may, of course, have additional functions, such as integrating, recording, amplifying, dispatching, etc., but primarily their purpose is that of measurement.

In power plants, and in fact generally speaking, measurements are made for four different purposes, as follows:

A. Measurements for accounting purposes.
B. Measurements for determining the performance and efficiency of equipment.
C. Measurements for insuring proper service requirements.
D. Measurements for testing the condition of equipment and for insuring safety.

To discuss and analyze the use and application of instruments more thoroughly let us consider a simple power plant, receiving fuel at one end and delivering electrical energy at the other as in Fig. 1. Here the only instrument necessary to determine the value of the plant, in terms of dollars and cents, is a cash register. A cash register is not ordinarily regarded as an instrument, but since it measures monetary operations it properly must be classified as an instrument. In this case it measures the difference between (a), the money spent for fuel, labor, supplies, maintenance, etc., and (b), the money received from the sale of power. This difference, profit or loss as the case may be, is a rough measure of the overall operating efficiency of the plant.



In practice, however, this simple system is hardly adequate. Among other shortcomings, the input and output readings are too widely separated. The cash register is an integrating meter—it does not indicate the efficiency of operation at a particular instant. What would be better for our purpose is an arrangement consisting of a coal meter, graduated to read the heat units supplied, and a wattmeter, also graduated to read the heat unit equivalent of the electric power delivered. This case is illustrated in Fig. 2.

Because this arrangement does not take into account such items as labor, cost of fuel, price received for power, etc., it gives a better measure of the overall thermal efficiency of the plant than the first arrangement. In a commercial application of this system in England the elements involved have been combined in a single instrument known as the Gilson "Efficiency Meter." This interesting though hardly precise form of power plant instrument (Fig. 3) was devised for the purpose of giving at any time an indication of the efficiency at which a plant is operating. The meter element consists of a movement similar to that used in a power factor meter, wherein a pointer takes up a position representative of the ratio of two currents flowing in separate windings. One of these windings is supplied with current whose value is controlled by the rate of fuel supply to the boiler, while the other receives its current from a transformer or shunt

n *the* POWER PLANT

Photo. Westinghouse.

on the main bus. The ratio of these two quantities as shown on the indicator will then be an approximate measure of the overall efficiency of the unit or plant under consideration. The limitation of this type of instrument lies in the precision with which the input energy may be measured.

Even if we assume the Gilson system to be accurate, it still leaves much to be desired. Insofar as profit or loss are concerned it is true we are interested only in overall efficiency but if this efficiency is low, the information given by the Gilson meter is of little value since it presents no clew as to where improvements may be effected. It tells nothing about service requirements, condition or efficiency of equipment.

Obviously, other instruments are needed in the operation of a plant. It may be desirable or necessary to know the efficiency of each piece of apparatus or of groups of apparatus. As an example, we may measure the difference between the amount of heat delivered to the boilers in the coal and that which leaves in the steam, and so obtain a value for the overall boiler efficiency. But here again, if the resulting value is low and we wish to raise it, it becomes necessary to measure other things—the stack losses, or the radiation losses through the furnace walls. Hence, we need instruments for measuring the heat content of the flue gases and for analyzing their composition, etc.

Similarly, for determining the performance of the forced or induced draft fans, instruments are necessary for measuring the input to the motor or turbines driving these fans and other instruments are needed to measure the quantity of air delivered, its pressure and temperature. And so throughout the entire plant from the coal pile to the transmission line, the performance of each machine may need to be measured separately.

In practice, however, such thorough measures are not normally necessary nor expedient and a middle course must be followed in the selection of instruments needed for satisfactory operation. No hard and fast rule can be laid down stating what instruments must and must not be used since the problem is one influenced very much by local conditions. In the pages that follow, it is our purpose to present as far as possible, the factors involved and what methods to use in the proper selection and application of instruments.

The intelligent application of instruments requires something more than a mere familiarity with their principles and operation, it requires an insight into their function as it affects the operation of the plant as a whole and upon what use is made of the information which instruments provide. It is better to install too few instruments than to install more than can be

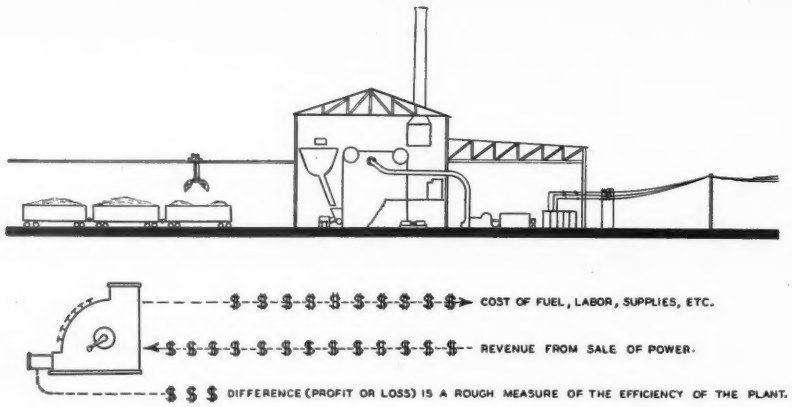

COST OF FUEL, LABOR, SUPPLIES, ETC.
REVENUE FROM SALE OF POWER.
DIFFERENCE (PROFIT OR LOSS) IS A ROUGH MEASURE OF THE EFFICIENCY OF THE PLANT.

Fig. 1. The only instrument necessary to determine the value of this plant in terms of dollars and cents is a cash register measuring the amount spent for coal going into the plant and the amount received from the sale of electrical energy leaving the station. This provides a rough measure of the overall efficiency

taken care of by the plant organization. There are, of course, certain instruments which all plants, regardless of size or character, should have installed, but there are many others which should be installed only after a full consideration of their value and usefulness.

Thus far in the discussion we have considered almost entirely the measurement of efficiency or performance, that is, that class of measurements included in group (B) in our classification. Such measurements of course can have different objects; they may be made with the idea of improving the performance or they may be made for accounting purposes. Insofar as the instruments involved under groups A and B are concerned, it is difficult to differentiate between them because an instrument which provides information for accounting purposes may also provide information for determining efficiency. In fact, this applies also to the other classifications, C and D.

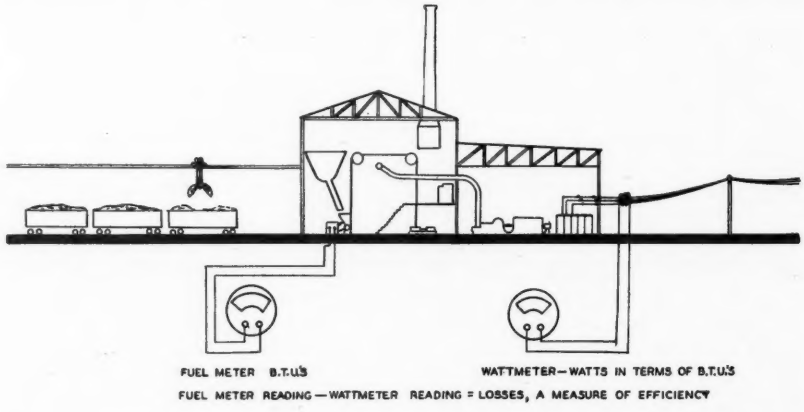
There are a large number of measurements which have for their purpose the insurance of proper service conditions. Such, for example, is the measurement of frequency on the electrical system, the measurement of water temperature and steam pressure and the measurement of illumination intensity. These measurements may also enter into safety and efficiency considerations but as ordinarily made they are for the purpose of maintaining proper service conditions.

the subject, it will be to advantage to consider this classification of measurements in greater detail.

The operation of any power plant, even the simplest, requires that certain data be recorded from which the cost of operation can be quickly and conveniently determined. This data is usually recorded in the engineers log and in reports which serve as the connecting link between the power plant and the accounting department. These reports enable the progressive manager or superintendent to lay his finger on the weak spot in the power generating process and to institute remedial action. Even where no formal report is required, the engineer should keep some form of log, no matter how simple, in order that he may have before him information which will permit him to investigate the resources of the equipment in his charge. The amount of detail contained in these reports to the management depends on the use to which they are put. If the total cost of fuel and wages and the amount of power generated and its cost per unit only is wanted, the report should include only these, but if detailed information regarding the amount of coal, oil, water and supplies used is required, the reports of course must be more elaborate. Usually the larger the plant and the more comprehensive its service, the more elaborate will be the reports required.

It is of course not our purpose here to discuss the

Fig. 2. Here we have replaced the cash register by two meters, one measuring the heat units delivered to the plant at one end and the other measuring the heat units in the electrical energy leaving the plant. The difference in the readings is a measure of the efficiency of operation



It must be evident, therefore that this classification applies only to measurement, not to instruments. Instruments can be classified in a different way as will be shown later, but before we discuss that phase of nature of the log sheets or report forms but inasmuch as the information on these logs and reports in many instances must be obtained from instruments, it is necessary to keep them in mind in any discussion of

instruments. As a rule the power plant log contains considerably more data than is entered upon reports to the management or to the accounting department. The accounting department being concerned directly with costs and not necessarily with the methods by means of which the cost figures are obtained, is not interested in records of steam temperature, draft pressure, CO_2 content of the flue gas, etc., but the engineer or the engineering department is vitally concerned with these factors as they are required in efficiency calculations. From this it is obvious that the measurements necessary for accounting purposes and those necessary for efficiency determinations can roughly be differentiated according to whether the data they furnish is to be included in the report to the accounting department or only on the engineer's log chart.

The items in which the accounting department is interested can be grouped under headings as follows:

1. Cost of fuel, water, oil, supplies, etc.
2. Cost of labor
3. Maintenance
4. Insurance, taxes, rent and interest on investment (fixed charges)
5. Cost of management
6. Cost of steam, power and other commodities delivered or purchased.

Insofar as instrumentation is concerned, we are interested only in three of these items, i.e., Nos. 1, 3 and 6. The data required under items 2, 4 and 5 are obtained without the use of instruments, unless we include such devices as time clocks, and mechanical office equipment, which however will not be done here. In arriving at the cost of fuel, oil, water, etc., it is necessary to obtain information from instruments of various types, scales, fluid meters, gages, hydrometers, counters, etc. Also in connection with maintenance of equipment, instruments are involved but not necessarily for accounting purposes. In electrical work, for example, it is necessary in order to maintain the proper condition of the equipment, to make insulation resistance tests but the data so obtained is of no interest to the accounting department. It is only when a device has to be repaired or replaced that the accounting department is interested in maintenance data. Measurements of insulation resistance are properly classified under item No. 4. It is evident, therefore, that for accounting purposes our consideration of instruments need be confined only to items 1 and 6 in the above classification.

In order to indicate more effectively how various types of measurements are grouped under the four headings of this classification of measurements, the following tabulations have been prepared. As will be noted in these lists a number of measurements appear under two or more headings.

1. Measurements for accounting purposes.

These include measurement of the quantity of coal, oil, water, gas, steam, air, refrigeration, electrical energy and measurement of power factor.

2. Measurements for efficiency purposes.

Rate of fuel feed, water flow; heat value of fuel; draft pressure; amount of air used; air temperature; fuel temperature; quantity, composition and temperature of flue gas; quality and composition of water; effect of chemical treatment of water; quality and quantity of steam; steam pressure; mechanical power of turbines, engines, motors; power factor.

3. Measurements for insuring proper service requirements.

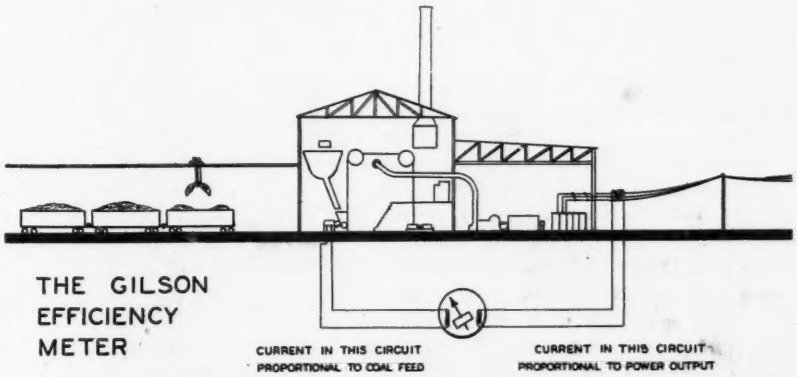


Fig. 3. In the Gilson system, the two elements involved in the arrangement in Fig. 2 are combined into a single instrument. This instrument has two windings, one supplied with current proportional to the rate of fuel feed, the other with current proportional to the electrical output of the station. The meter is calibrated to read the station efficiency directly in per cent

Pressure, temperature quality and quantity of steam and water; pressure temperature and quantity of air; smoke density; voltage; current; frequency; power factor; synchronism; balance of circuits; wave shape; measurements under abnormal and limiting conditions; quality and intensity of illumination; noise intensity; vibration; speed of equipment.

4. Measurements for testing the condition of equipment and insuring safety.

Pressure and temperature of air, gas, steam, water, oil; measurements of accuracy of all instruments; voltage, current, power; tensile, compressive and breaking strength of materials. Circuit constants—resistance, capacity, inductance; insulation resistance and breakdown; wave form.

This list includes all of the ordinary types of measurements necessary in the average power plant as well as a number of special measurements which might be made if occasion demands. While it is considerably more complete than ordinary operating requirements demand, it will serve as a guide or rather as a background in the selection of instruments for various types of plants. The actual selection of instruments for a particular plant is of course dependent upon local conditions and this question is discussed in considerable detail in the pages that follow, but no matter how local conditions affect the question of instrument selection, the underlying purpose of the instruments as outlined must not be lost sight of.

Photo. Courtesy General Electric Review.

INSTRU

10101.0101 ohms.

At the Century of Progress Exposition held in Chicago, people had the opportunity of viewing the marvels of this scientific age in a way that was never offered them before and in the two summers of its existence they came, in millions, from all parts of the world to see everything from the capture of a light ray from a star to the assembly of an automobile. There was a great display of interest in all the diverse and varied aspects of modern scientific and production methods.

There was one exhibit at this exposition, however, which was passed unnoticed by millions and with merely a glance by countless others because of its apparent insignificance, yet this was perhaps the most marvelous and amazing exhibit of the entire exposition. It consisted of a small, rather carefully made, plush-lined case, less than an inch thick—not a foot long, containing ten small rectangular blocks of polished steel. They were *gages*—a set of Johansson gage blocks.

LORD KELVIN used to say that "when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."

This utterance should command one's admiration for it is a simple expression of a great truth—a truth which takes on increasing significance the more we consider it. For measurement *is* the basis of all real knowledge, not only in science and engineering, but in other branches of human endeavor as well. Even in art and philosophy, measurement plays an important part, not to the same extent that it does in science but still of fundamental consequence.

In science and engineering, however, it is of the utmost consequence; indeed the rate of progress in science is in definite proportion to our skill and ability to measure things. No engineer travels very far along life's way until he finds he has to measure something. He uses the available means or, finding none, he tries to develop means.

Now, what was there so amazing, so marvelous about these blocks? Granting that they were nicely made and beautifully polished and that they could be used as measuring blocks, still that would hardly justify the importance attributed to them here. To one who knows the story of the Johansson Gage Blocks, however, these questions would not arise for he would know that without these gage blocks a vast part of the Century of Progress Exposition could not have been possible. Most of the fine machines and tools and instruments used in the manufacture of automobiles and other modern things could not exist were it not for the existence of these gages.

For these ten little blocks vary in size (progressively) by only *one millionth of an inch;* that is, each one is just exactly one millionth of an inch wider than the one next to it, and the opposite faces are exactly parallel. Indeed, at no point on the surface of any of these blocks is there a variation of over a quarter of a millionth of an inch! So perfectly flat are these

MENTS *and* MEASUREMENT

General considerations on the theory of Measurement. Its importance, methods involved. Standards of measurement. The use of standards in the application of instruments. The definition of instruments and their classification.

pieces of metal that if they are thoroughly cleaned and slid one on the other with a slight inward pressure, they stick together as if they were magnetized. In a demonstration before the Stockholm Technical Institute in 1917 Johansson "wrung" two blocks together, the sizes of the two faces being approximately one half a square inch—and the contact sustained a weight of 220 pounds! This weight was more than 30 times the atmospheric pressure during the demonstration. The explanation for this remarkable adhesion probably lies in the attractive forces existing between the molecules in the respective faces of the two blocks.

The story of these gage blocks and of the man who discovered how to make them is a fascinating one. They are of inestimable value in modern manufacture and, today, they are used as the standard of measurement in industry the world over. Thanks to the insight of Henry Ford into the problem of measurement and to his early appreciation of Johansson's genius, today at the Ford Engineering Laboratories at Dearborn, Michigan, the Johansson blocks are made for the entire continents of North and South America. With these gages, Ford and other automobile manufacturers put out an automobile within reach of every family. Because of these gages, the shaft of a hydraulic turbine made in Switzerland and that of an electric generator made at Schenectady or East Pittsburgh, fit perfectly when they are assembled in South Africa.

We have discussed the Johansson gages in some detail because they represent perhaps the greatest achievement in the science of measurement ever made. There have been others in the measurement of electricity and of time which are equally wonderful in point of magnitude but their application is less universal.

Principles of Measurement

The science of measurement involves two fundamental principles, first, method, and second, standards. In other words, first we must have some idea, some theory or method of making a measurement, and second we must have a unit on which to base our measurement. In the measurement of length, for example, first we have a theory or a postulate under which we assume that things equal to the same thing are equal to each other. This is fundamental, unless we can accept that, we cannot hope to succeed in what we are trying to do. If we assume its correctness however, the theory of measurement becomes simple and we only require a suitable standard with which to compare all our measurements. Such a standard is a foot rule, or the international meter bar at Paris, or the absolute wave length of the red cadmium line in the spectrum. These three standards represent three stages in the development of measurement, the first derived simply from the length of the human foot, the second, from the size of the earth (theoretically) and the third from an exact knowledge of the theory of light and matter and involving the development of the science of spectroscopy.

The standard of length utilizing a wave length of light represents a complex development in the art of measurement, one, in fact, involving immense mental and physical effort over centuries of time. It also involves an amazing extension of our physical perception. In this case, the method and the unit are inextricably interwoven, one is impossible without the other. The method involves the science of optics; the unit, chemistry and the theory of light.

It must be quite evident then, that the question of "units" or "standards" is of the most fundamental importance in the theory of measurement and instruments. The moment any branch of science begins to develop and attempts are made to evaluate quantities, it becomes necessary to select for each measurable magnitude a unit or standard of reference. While there is nothing to prevent us from selecting these fundamental quantities in a perfectly arbitrary and independent manner, the progress of knowledge is greatly assisted if all the measurable quantities can be brought into relation with each other by so selecting the units that they are related in the most simple manner, each to the other, and to one common set of measurable magnitudes called the fundamental quantities. The Johansson gages described above, though marvelously accurate, are not the absolute units used in the measurement of length—they are practical units which are made in terms of the absolute unit of length.

The coördination of units has been greatly aided by the knowledge that forms of physical energy can be converted, one into the other, and that the conversion is by definite rules and amount. The mechanical energy associated with moving masses, for example, can be converted into heat and so, heat can be measured in mechanical energy units. Again, the fact

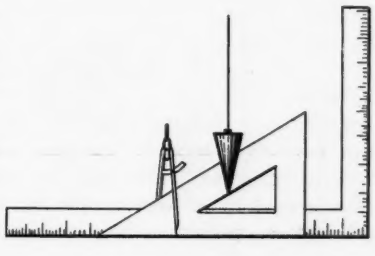


Table Showing the Classification of Measurements

1. MEASUREMENT of QUANTITY

A (ABSOLUTE)	SOLIDS, LIQUIDS, GASES			COAL, FUEL OIL, GAS, WATER, OIL FOR LUBRICATION, CHEMICALS FOR F.W. TREATMENT	SCALES, COUNTERS, STRAIGHT EDGES, DEPTH GAGES, CUBIC & VOLUMETRIC MEASURES
	ENERGY	KINETIC	RADIATION	HEAT	CALORIMETER
				LIGHT	PHOTOELECTRIC METERS, PHOTOMETERS, PHOTOCHEMICAL METERS
				ELECTROMAGNETIC	ELECTRONIC MEASURING DEVICE
				SOUND	SOUND INTENSITY METERS
			MECHANICAL	MOVING MASSES – FLYWHEELS, ETC.	SCALES, TACHOMETERS, RULERS
			ELECTRICAL	ELECTRICAL ENERGY	GALVANOMETERS, AMMETERS, WATTHOURMETERS
		POTENTIAL	MECHANICAL	IN MASSES — IN SPRINGS	SCALES, RULERS, WEIGHTS
			ELECTRICAL	ELECTRIC-CHARGES	ELECTROSCOPES, VOLTMETERS, POTENTIOMETERS
			MAGNETIC	MAGNETIC FIELD	FLUXMETER
B (WITH RESPECT TO TIME)	LIQUIDS			WATER, OIL, BRINE	FLOWMETERS, WEIRS, CURRENT METERS
	SOLIDS			COAL	INTEGRATING SCALES
	GASES			AIR, GAS FUEL, STEAM	FLOWMETERS
	POWER	MECHANICAL		ENGINES, ROTATING SHAFTS	INDICATORS, TORSIOMETERS, PRONY BRAKE, DYNAMOMETERS, ELEC. GEN.
		ELECTRICAL		GENERATORS, MOTORS, BATTERIES	WATTMETERS, VOLTMETERS, AMMETERS

2. MEASUREMENT of QUALITY

HEAT VALUE	COAL, OIL, GAS	CALORIMETERS
DENSITY—CONCENTRATION	OIL, WATER, GAS, SMOKE	HYDROMETERS, CHEMICAL INDICATORS, SMOKE INDICATORS
COMPOSITION—ANALYSIS	FLUE GAS COAL, GAS	ORSAT, CO & CO_2 METERS BOMB CALORIMETER
VISCOSITY	OIL	VISCOSIMETERS
MOISTURE	IN AIR IN STEAM	HYGROMETERS, PSYCHROMETERS CALORIMETERS
ELECTRICAL CONSTANTS	RESISTANCE	VOLTMETER, AMMETER, WHEATSTONE BRIDGE, OHMETER
	INDUCTANCE	INDUCTANCE BRIDGE
	CAPACITY	CAPACITANCE BRIDGE
RADIATION	ILLUMINATION	SPECTROSCOPES — SPECTROMETERS
	HEAT	THERMOMETERS, PYROMETERS
	SOUND	TUNING FORKS, ELECTRON OSSCILLATORS

3. MEASUREMENT of CONDITION

TEMPERATURE			WATER, OIL, STEAM, AIR, WINDINGS, COMBUSTION, BRINE, ETC.	THERMOMETERS, PYROMETERS, ELECTRIC RESISTANCE, THERMOCOUPLES
PRESSURE			AIR STEAM WATER GAS	BOURDON GAGES, DIAPHRAGM GAGE, MANOMETERS (MERCURIAL-WATER)
SPEED		ROTATIONAL		COUNTERS, TACHOMETERS, STROBOSCOPES, PHOTOGRAPHIC RECORDERS
		TRANSLATIONAL		SPEEDOMETERS, CHRONOGRAPHS
		VIBRATION	MECHANICAL	HARMONIC INDICATORS
			ELECTRICAL	FREQUENCY METERS, WAVE METERS, OSCILLOGRAPH
POTENTIAL			SMALL VOLTAGES	STANDARD CELL, POTENTIOMETER, VACUUM TUBE VOLTMETER
			MEDIUM VOLTAGES	VOLTMETER
			HIGH VOLTAGE	ELECTROSTATIC VOLTMETER
			SURGES	KLYDONOGRAPH, CATHODE RAY OSCILLOGRAPH
DISPLACEMENT	IN SPACE		OF MECHANICAL PARTS	GAGE BLOCKS, RULERS, TRANSITS, MICROMETERS
			OF ABSTRACT QUANTITIES	PLANIMETERS, SURVEYING INSTRUMENTS
	IN TIME		OF VOLTAGES	POWER FACTOR METERS, VOLTMETER, AMMETER, WATTMETER
			OF MECHANICAL FORCES	OSCILLOGRAPHS, CHRONOGRAPHS, CLOCKS

that the maintenance of an electric current requires energy and that when produced its energy can be wholly utilized in heating a mass of water enables us to express the energy required to maintain the current in terms of the energy of a moving mass. A knowledge of these transformations of energy is of value not only in the coördination of units but also in the design of instruments. As we shall see later, in many instances, heat is measured by electrical instruments and in others electricity is measured by "thermometers," or by photometers (light meters).

The modern system of absolute physical units is founded upon dynamical motions. The postulate which lies at the base of this system and in fact upon the whole study of physics is that in the ultimate issue we can describe all phenomena in terms of length, time and mass.

Fundamental Units

There are two systems of fundamental units in common use, the British system, having the yard and the pound as standard units of length and mass, frequently called the foot-pound-second (FPS) system; and the centimeter gram-second (CGS) system, having the centimeter and gram as standard units of length and mass and known as the metric system. The fundamental unit of time is the same in both systems, namely, the "mean solar second," one 86,400th of a mean solar day.

Upon these concepts, length, mass and time are based all the various units used in practical physical measurement. The practical units fall in various classes of subdivisions and species and various special empirical or hybrid systems have evolved but in the ultimate analyis, all of these systems can be expressed in terms of the three absolute concepts listed above. In the case of electrical measurements two systems are possible, the electromagnetic system and the electrostatic system. The electromagnetic sub-system was established on the basis of the unit magnetic pole such that it repelled its prototype at a distance of 1 cm. with a force of 1 dyne. The dyne, of course, is derived from the centimeter, gram and the second. The electrostatic sub-system was similarly established on the basis of the unit quantity of electricity, such that it repelled its prototype at a distance of 1 cm. with a force of 1 dyne.

It is not our purpose here to discuss the various systems of units in use even if we had space available to do so, but we do want to emphasize the importance of these units in the design and application of instruments. The accuracy of all instruments depends upon the existence and availability of these units and their sub-standards, and their development for practical application in the use of instrument calibration represents an achievement of enormous importance in the art of measurement.

Standards of Resistance

Consider for a moment the rather fantastic photograph which appears at the head of this article. Aside from its striking photographic composition, this picture represents as high a point in the measurement of electrical constants as do a set of Johansson gages in the measurement of length. These standards of resistance shown in this photograph as set up form a resistance of exactly 10,101.0101 ohms. They are part of the standards maintained in the General Engineering Laboratory of the General Electric Co. and form the basis of comparison for all resistance measurements in all branches of manufacture of that company. Throughout the electrical industry, the question "How many ohms?" is ever recurrent, and each time an answer must be directly or indirectly traceable to certified resistance such as those illustrated. Otherwise, hopeless confusion would result.

The development of instruments proceeds, hand in hand so to speak, with the development of standards, and of course also with the development of our knowledge of physics. Most of our measurements today are in a region far beyond the limits of our perception. For example, a common house-fly alights on a table. We hear nothing, indeed all humans in the room testify that there has been no noise. But in a noted laboratory the tread of the house-fly has been amplified until it sounds like a hoofbeat. The noise is there but human ears cannot hear it. Again, as evening comes we look upward at the sky and pause to admire the stars. We know a few of them and recognize their pattern but between them all seems dark and empty. But look through a telescope! There, between the stars where all seemed dark and empty, a thousand flares are burning. They have been there during all the ages of the earth but until man developed instruments, we could not know they were there.

The telescope is a marvelous instrument for it tells us much. And yet, in another sense it tells us very little. Attach a spectroscope to the end of the telescope. Instantly a whole new vast field of knowledge becomes available. The entire history of the Universe opens up and we know not only the condition and the composition of the stars, but we are able to determine their speeds of rotation and of translation through space in our line of sight. Practically all of what we know about the Universe has been determined by instruments.

Sensitivity of Modern Measuring Instruments

These are typical of countless other examples that we might cite to show how instruments have added to our knowledge of all things. Not many decades ago, a Wheatstone bridge, a voltmeter and an ammeter sufficed for electrical measurements. Today the scope has been amplified many fold and we require standards of such accuracy as those referred to above. Along with the production of an increasing number of kinds of measuring devices has come the necessity for extending the capability of instruments. As an example of accomplishments along this line may be mentioned the supersensitive amplifier which will measure 0.000,000,000,000,000,01 amp. or 1,000,000,000,000,000 ohms; the surge crest ammeter which functions in one half of a millionth of a second and the photoelectric controller which will hold temperature constant to within plus or minus 0.004 deg. C.

These limits of accuracy in instruments are far

beyond anything usually required in ordinary power plant practice, but we refer to them to show the vast scope of instrumentation in the present day world. This, however, is only part of the story. The increase in the scope of instrumentation has not been alone in the number of devices in use. The watthour meter is an excellent example. The use of this instrument has increased to enormous proportions. In this country alone it measures two billion dollars worth of electric service.

It is superfluous perhaps to point out the need and value of instruments in the modern world to anybody connected with the generation of power. For it is impossible to operate even the simplest kind of a plant without at least some instruments. Imagine operating a boiler without a steam pressure gage. The argument might be advanced that a boiler *could* be operated without a pressure gage by keeping the pressure just below the pop-off point of the safety valve. The answer to this is, of course, that the safety valve is itself an instrument—a pressure gage which automatically opens when it measures pressure of a predetermined degree.

What Are Instruments?

This brings us to the question, "What is an instrument?" If a safety valve is to be considered then so also is a pump governor, a draft regulator or a voltage regulator. All of these devices have measurement as a part of their function.

In the control of any process, regardless of its nature, a measuring device may function in two ways:

1. It may give visual indication of events or conditions which may govern the manual adjustment of apparatus controlling these events or conditions.
2. It may initiate actions which automatically adjust equipment controlling events or conditions.

Obviously if we are to include the second principle in our conception of instruments, we must include all types of automatic equipment such as relays, automatic regulators, starting devices, speed control apparatus and all sorts of protective equipment, fuses, safety valves, lightning arrestors, circuit breakers. Since this is entirely too broad a classification for consideration in this issue, we shall at the outset limit our definition of an instrument to include only those in the first group, that is those devices which provide information regarding conditions or events by means of which we may govern our actions with respect to these conditions or events.

Classification of Instruments

Having in mind clearly what is meant by an instrument we can now consider the classification of instruments. In general, instruments can be grouped under three headings, as follows:

A. Instruments for the measurement of quantity.
   1. Absolute.
   2. With respect to time.

B. Instruments for the measurement of quality.

C. Instruments for the measurement of condition.

As indicated instruments for the measurement of quantity (Group A) can be divided into two groups, first, those for the measurement of quantity in bulk or in total, and second, those for the measurement of quantity with respect to time. The first subdivision includes such devices as scales, cubic measures, integrating devices, etc., while the second has reference to such instruments as flowmeters. These are the instruments used primarily in accounting and cost finding but are also used in efficiency determinations.

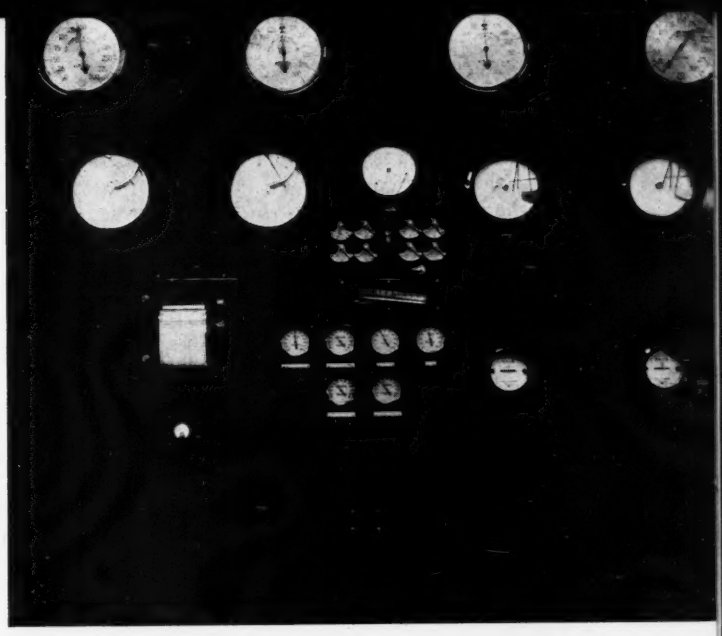
The next group (B) includes instruments which measure the quality of things and under this grouping may be listed calorimeters, gas analyzers, hydrometers, photometers, etc. These instruments are usually used in maintaining proper service requirements.

Finally we have the group used in measuring the condition of things, temperature, pressure, speed, voltage, etc., and here we may list thermometers, voltmeters, pressure gages, etc., instruments used primarily in maintaining safe operating conditions but of course also useful for other purposes.

With these three classifications, it is possible to arrange all instruments in a tabulation such as is shown in the accompanying classified table. While this table is not presented as being comprehensive, i.e., including all instruments, it does show all instruments normally used in power generation and distribution. Most of the listings are quite obvious, but the question of speed may require some comment. Speed, although listed under measurement of condition, might also be classified under 1B, that is as a measurement of quantity with respect to time. Since speed, however, has no particular significance when considered apart from matter, we have regarded it as a condition of matter rather than as an absolute entity. Frequency meters and tachometers, however, in a certain sense may be regarded as instruments for the measurement of quantity (revolutions, feet or cycles) per unit of time.

Many of the instruments listed in this table are of a complex and highly specialized type and of course are used in power plant work only in exceptional instances. Others are laboratory instruments, and though one engaged in power plant work should be familiar with their principles, they are not ordinarily used. In the pages that follow we shall consider largely the instruments which are actually used in ordinary present day practice.

Pacific Gas and Electric Co. has made cash awards to employes for practical suggestions to improve operating methods as follows: To H. S. Markey, assistant superintendent of station P in San Francisco, $50 for plan to salvage more condenser tubes; to L. V. Rebois, machinist at station A, San Francisco, $25 for design of set of tools to facilitate changing condenser tubes; to H. C. Moyer, foreman, electric department, Oakland, $10 for design of safety-first wrench to operate underground circuit cutouts from outside the manholes; to T. P. Perkins, superintendent of gas distribution, Stockton, $100 for method of improving pressures in gas mains so as to give better service during periods of peak load. These awards are in addition to a payment of $2.50 for each suggestion submitted by an employe, that is considered meritorious.



Instrument panel of the University of Minnesota Farm School boiler room. The top row of gages is made up of four pressure gages for the four boilers. On the left side, under these gages, are two steam flow meters for boilers Nos. 3 and 4, while a four pen CO_2 and flue gas recorder is directly under these instruments. On the right side of the panel are two meters recording flue gas temperature, CO_2 and steam flow, with two steam flow integrators directly beneath serving boilers Nos. 1 and 2. In the center of the panel beneath the boiler gauges is a recording pressure gauge. Below this is a draft gauge connected to the furnace and uptake of each boiler and controlled by the panel mounting valves above the draft gage. The six gages and five control knobs under this group form a part of the automatic control used in connection with the four pulverizers. (Photo courtesy L. L. Wood.)

Pressure Measuring Instruments

Few Fundamental Types Cover Entire Pressure Range from Zero to Several Thousand Pounds

PRESSURES, as commonly found in the power plant range from a minimum of about 0.5 lb. per sq. in. absolute (approximately 1 in. of mercury absolute pressure or about 29 in. of vacuum) to a maximum of about 1500 lb., a ratio of over 3000 to 1. Fortunately, however, the necessary measurements are grouped into three general classes: vacuum readings of from 24 to 29 in.; draft readings from a few inches of water below atmosphere to a few inches of water above atmosphere; miscellaneous pressure measurements of water, steam and other fluids from a few pounds up to several hundred pounds depending upon the details of the plant and the steam pressure used. The complete range can be covered by a few types which meet the fundamental requirements of ruggedness, accuracy and adaptability to indicating and recording mechanisms.

Probably the most widely known and commonly used instrument is the Bourdon gage which was introduced into this country during the early part of the last century. It is made in a variety of designs and of different materials to meet service conditions. As shown by Fig. 1, it consists fundamentally of a curved spring or tube with one end firmly fastened to the frame, the other free to move but linked to a pointer spindle through a gear segment and pinion.

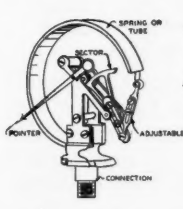


Fig. 1. The Bourdon simple gage

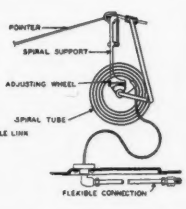


Fig. 2. The tube extended to form a spiral

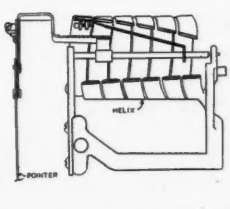


Fig. 3. The tube used as a helix

This tube is made of brass, bronze or steel, is usually of elliptical cross section although a round tube is sometimes used especially for the higher pressures. The material used depends primarily upon the pressure range and service. Steel is used for higher pressures and of course for services such as ammonia which corrodes brass.

When the tube or spring is subjected to pressure, it straightens out because the tube tends to assume a round cross section and because the area of the outside circumference is longer than the inside thus giving an unbalanced force outward. This tendency to straighten out is proportional to the pressure inside the tube or more correctly to the pressure difference between the inside and outside of the tube. As the tube straightens out, the pointer sweeps over the graduated face of the gage dial.

This type of gage gives the so-called gage pressure, that is, difference between the air pressure surrounding the tube and that inside the tube. To get the absolute pressure, necessary in so many engineering calculations, it is necessary to add to the gage reading the barometric pressure reduced to the same units. The barometric pressure varies with the elevation or altitude, a fact that must not be forgotten when using steam tables, calculating air compressor performance or dealing with Diesel engines. Bourdon pressure gages usually begin at zero and are made in a com-

plete range of pressures from a few pounds up to several thousand pounds.

If the spring or tube be subjected to a vacuum the tube tends to bend inward, i.e., curl up more, so that it can also be used as a vacuum gage. In this case the mechanism is made so that the hand starts at zero and moves counterclockwise (as in the pressure gage). The face is commonly graduated for a maximum reading of 30 in. of mercury. These two gages, i.e., pressure and vacuum, may be combined in a so-called compound gage in which pressures are shown by clockwise movement of the pointer and vacuums by counterclockwise movement, the indications in both cases being of course the pressure variation from atmospheric so that barometric pressure must still be considered when calculating absolute pressure.

Although the spring shape shown by Fig. 1 is perhaps the most common, the same principle is used with other shaped springs. For instance the spiral spring shown by Fig. 2 and the helical spring shown by Fig. 3. Another commonly used pressure measuring element is the diaphragm, best known perhaps in connection

Fig. 4. A simple form of single diaphragm gage

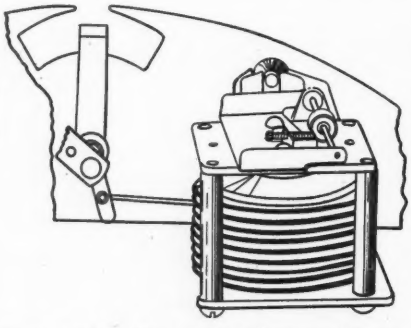


Fig. 5. The bellows may be considered as a multiple diaphragm

with the aneroid barometer. An elementary form of diaphragm gage is shown by Fig. 4. Pressure under the diaphragm bends it upward and this movement is transmitted to the pointer by a gear segment and pinion. The diaphragm being of corrugated metal is in itself a spring which resists the distortion caused by pressure. An auxiliary loading spring may or may not be used.

The diaphragm does not, of course, have to be made of metal, Fig. 6 illustrating the details of a differential draft gage utilizing a slack leather diaphragm. In this particular instrument movement of the diaphragm, either way from normal, is resisted by a spring, the movement of which is transmitted to a pointer. This type of gage can obviously be made for indications of positive or negative pressures as well as for the differential pressures, and as the force exerted on the spring is proportional to the area of the diaphragm, the sensitivity of the instrument, for low pressures, can be increased by using a larger diaphragm.

The bellows spring movement, shown in Fig. 5, may perhaps be classified as a multiple diaphragm. Pressure variations cause a contraction or expansion of the bellows and this movement is transmitted to a pointer by suitable linkage. The bellows may be used alone or in conjunction with springs.

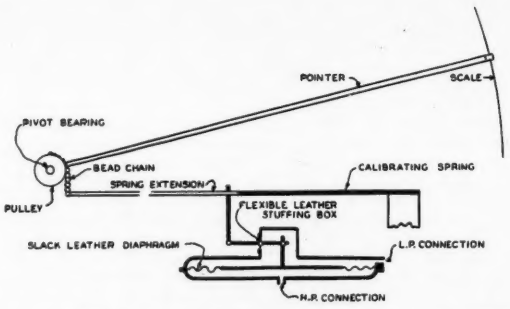


Fig. 6. A leather diaphragm as used in a differential draft gage

The liquid sealed bell is also an accurate and popular design for measuring low pressures such as are commonly encountered in draft gage practice. Figure 7 shows one design, of the single pointer, oil sealed type, for measuring negative pressures. With a draft or negative pressure applied to the end of the bell through the small pipe, the bell is forced down by the atmospheric pressure and the oil seal is lifted up to a height corresponding to the draft intensity. As the bell is forced down the pointer is displaced from its zero position and the movement of the bell is opposed by the gravity pull of the counter-weights. The same type of gage may be used for indicating low positive pressures as well. The pressure or suction range is determined by the length of the seal and the density of the liquid used. Plus or minus 8 to 12 in. of water is the usual maximum for oil filled gages. This range may be increased materially by using mercury. A pressure indicating gage of this kind suitable for pressures up to 25 in. of water is shown by Fig. 8. As the bell rises due to the internal pressure it tips on the knife edge and this movement is opposed by gravitational pull of the pendulum weights which are rigidly attached to the crosspiece and tip from the vertical with it.

Then there is the large group of pressure or head measuring instruments known under the general name of manometers. In principle these devices consist of balancing a column of liquid against the pressure to be measured. From the height of the column and density of the liquid the pressure can be calculated.

Most widely used of this type of instrument is the mercury column barometer, a cistern type manometer shown, in elementary form, by Fig. 9A. The glass tube 33 or 34 in. long is filled with mercury and inverted

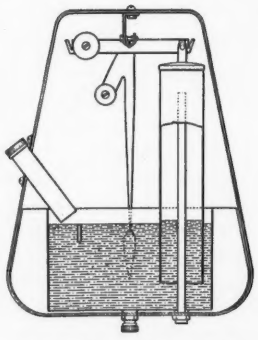


Fig. 7. An inverted bell, liquid sealed, negative pressure, draft gage

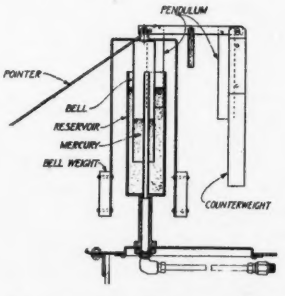


Fig. 8. A positive pressure draft gage using mercury to seal the inverted bell

Fig. 9A. An elementary barometer

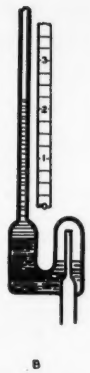


Fig. 9B. Two fluid cistern manometer

Fig. 9C. The usual U-tube manometer

Fig. 9D. Two fluid inverted manometer

in a well of mercury. By leaving the well open to the atmosphere the height of the mercury column can be read in inches on the attached scale and the pressure calculated. If the top of the tube at B is left open and a pressure connection added at A, a typical cistern type manometer results. By leaving A open and attaching the connection at B, vacuum instead of pressure may be read.

From readings of the height of the mercury column, pressures or vacuums can be calculated from the relation: 1 in. of mercury equals 0.49 lb. per sq. in. or 13.6 in. of water. If water is used in the manometer instead of mercury the pressures can be calculated from the same relation which transposed is 1 in. of water equals 0.036 lb. per sq. in. or 0.074 in. of mercury. For reading very low pressures such as draft gages, the scale is sometimes magnified by using an inclined tube and graduated scale as shown by Fig. 10.

Table I. Average barometric pressures for different elevations above sea level

Elev. above sea level	Atmospheric pressure in. of Hg. at 32 deg. F.	Lb. per sq. in.
0	29.92	14.70
1,000	28.85	14.17
2,000	27.82	13.67
3,000	26.82	13.17
4,000	25.84	12.69
5,000	24.90	12.23
6,000	23.98	11.78
7,000	23.09	11.34
8,000	22.23	10.92
9,000	21.39	10.51
10,000	20.58	10.11
12,000	19.03	9.35
14,000	17.57	8.63
16,000	16.21	7.96
18,000	14.93	7.33
20,000	13.74	6.75

Oil, carbon-tetra-chloride, etc., with specific gravities of less than unity is sometimes used as another method of multiplying very low pressure readings. When using fluids other than water the readings in inches can be converted to pounds per square inch by multiplying the specific gravity of the fluid by 0.036. Still another method is by using a cistern type, two fluid manometer as shown by Fig. 9B. The rise of the heavier liquid in the bottom, for instance mercury, causes a considerably greater rise in the lighter liquid, the multiplication depending upon the relative size of the bores of the tube and the densities of the liquids.

When measuring water pressures it is not practical to keep the water out of the manometer and a U-tube of the type shown by Fig. 9C is commonly used with water on top of the mercury. The head H of the mercury must be corrected for the corresponding water leg on the other side of the U-tube, so that under these conditions 1 in. of mercury as read on the manometer equals 0.454 lb. per sq. in. or 0.926 in. of mercury or 12.6 in. of water. Reading pressures of more than 15 or 20 lb. above the atmosphere would require excessive mercury columns, which of course limits the pressure range for which they are practical.

Differential pressures, however, may be read at higher pressures, up to the strength of the manometer glass, by using an arrangement such as shown by Fig. 9D. This is an inverted U-tube in which air under pressure may be introduced at D to bring the ends of the column within visible range. Sometimes liquids of various specific gravities are used on top instead of air. By careful choice of liquids practically any magnification of scale can be obtained, for instance with oil of a specific gravity of 0.90 on top of water the manometer would read ten times the normal pressure differential measurement in inches of water.

Multipliers for converting readings of barometers and manometers of various types as given by Table I taken from the A.S.M.E. Test Codes, the actual manometer reading to be multiplied by the multipliers as indicated to give desired results. As used in the table, d refers to the density of water in pounds per cubic foot which ranges about as follows: 50 deg. F., 62.41; 60 deg. F., 62.37; 70 deg. F., 62.31; 80 deg. F., 62.23. The correction for barometer reading mentioned in the table is a deduction equal to P (t — 32) ÷ 10,000 where P is the actual reading in inches of mercury and t is the actual temperature in degrees Fahrenheit.

Atmospheric pressure, at sea level, is usually taken as 14.7 lb. per sq. in. absolute but this decreases rapidly with the elevation above sea level. This change is shown by Table I for elevations of from sea level to 20,000 ft. at which point the barometric pressure is but 6.75 lb., a change of almost 8 lb. per sq. in. For ordinary engineering work these figures are close enough, especially if used in connection with Bourdon gage measurements. For accurate work the barometric reading, suitably corrected for temperature as explained above, should be used.

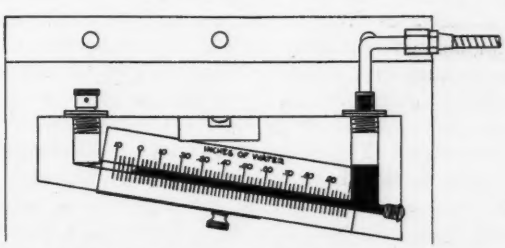


Fig. 10. An inclined draft gage allows closer reading because of the extended scale

Table II. Multipliers used for converting manometer readings from one set of units to another

	Instrument	Reading	Remarks	Multipliers for reducing readings to: Lb. per sq. in.	Inches mercury	Feet of water
1	Barometer Mercury gage Mercury U-tube	Inches mercury corrected to 32 deg. fahr.	Correction	0.4912	1.00	$70.74/d$ exactly. 1.134 for water at usual room temperature
2	Mercury gage Mercury U-tube	Inches mercury at t deg. fahr.	Use actual reading at actual temperature t deg.	$0.4912 \times \left[1.0 - \frac{(t-32)}{10{,}000}\right]$	$1.0 - \frac{(t-32)}{10{,}000}$ for inches mercury at 32 deg. fahr.	$\frac{70.74}{d} \times \left[1.0 - \frac{(t-32)}{10{,}000}\right]$
3	Mercury gage Mercury U-tube Barometer (in exceptional cases)	Inches mercury at usual room temperatures	Use uncorrected reading. Results are accurate for temp. of 56 deg. and closely approximate for usual room temperatures	0.49		1.132 for water and mercury at usual room temperatures
4	Mercury U-tube reading hydraulic pressure above atmosphere	Inches between levels of mercury in the two legs. Usual room temperatures	Water on top of lower column only, completely filling the pressure pipe. The result is the pressure at the base of a column of water extending to the level of the zero of the mercury tube.	$0.49 - \frac{0.036}{2} = 0.472$	1.00 − 0.037 for inches mercury at usual room temperatures	1.090 for water and mercury at usual room temperature
5	Differential mercury U-tube reading difference between two hydraulic pressures both above atmosphere	Inches between levels of mercury in the two legs. Usual room temperatures	Water on top of both columns completely filling both pressure pipes. Pressure is given between two points at the same level	$0.49 - 0.036 = 0.454$	1.00 − 0.074 for inches mercury at usual room temperatures	1.048 for water and mercury at usual room temperatures
6	Water U-tube or water gage	Inches water at t deg. fahr.	Work requiring a precision gage and precise computations.	$\frac{d}{1728}$	0.001178 d	1/12 for same temperature of gage and column
7	Water U-tube or water gage	Inches water at usual temperatures	For usual engineering work	0.036	0.074 for inches mercury at usual room temperatures	1/12
8	Bourdon pressure gage	Lb. per sq. in.	Reading to be corrected per the gage calibration	1.00	2.036 for inches mercury at 32 deg. fahr. 2.04 for inches mercury at usual room temperatures	$144/d$ exactly. 2.31 for water at usual room temperatures

Gages should, of course, be calibrated frequently as they are often subjected to continuous or intermittent vibration. Bourdon gages are usually calibrated by means of a dead weight tester, or for high pressures, a hydrostatic tester which eliminates the necessity for handling a large number of heavy weights. A dead weight gage tester consists essentially of an oil chamber with three connections, one for the gage, one with a close fitting lapped-in piston and one with a threaded plunger.

The gage is screwed on the tester and the desired number of accurately made weights added to the top of the piston. The plunger is then screwed in until the oil pressure lifts the piston and weights. These should be kept spinning during the calibration so as to make sure that they are lifted free of the support. The tester is, in effect, a hydraulic pressure machine, the weights and pistons giving the carefully calibrated test pressures. The hydrostatic tester is substantially the same as the dead weight tester with a scale or beam arm added to reduce the number of weights needed.

Another method is to compare the gage with a carefully calibrated test gage kept for that purpose. Vacuum gages, draft gages and inclined manometers can be most conveniently calibrated by means of a water or mercury column instead of a test gage.

Springs in pressure gages should always be protected against direct contact with the steam as the high temperature causes distortion and will often permanently ruin a gage. The necessary protection can be made by means of a pipe loop or bend so arranged that the condensing steam will fill it with water and prevent the direct entrance of the steam to the gage itself. Unless properly drained, beyond the protecting bend or syphon, the gage lines may be the source of considerable error due to the head of water which collects in the pipe.

If the gage is below the point where the steam pressure is being measured a head of water will build up in the pipe and the gage will read high. If the gage is installed above the point, with the line not properly drained back to the header, the gage will read low. Since a head of water 2.31 ft. high exerts a pressure of 1 lb. per sq. in. suitable correction can be made to the gage reading to arrive at the correct pressure existing at the point where the pressure measurement is desired.

PUBLIC LIBRARY
DETROIT MICH.

Temperature Measuring Instruments

Thermometers and Pyrometers in Rugged, Accurate Commercial Designs, Cover Entire Temperature Range Encountered in Plant Practice

TEMPERATURES commonly met with in power plant practice range from a few degrees above freezing to 700 or 800 deg. F., although in exceptional cases this range may be considerably extended in either direction. Instruments for measuring these temperatures have been divided by common usage into two broad but not very definite classifications, thermometers and pyrometers. As ordinarily used, the latter refer primarily to the high temperature devices, i.e., the thermocouples, optical and fusion cone methods.

For convenience, these two general classifications can be broken down into a number of sub classifications based on the methods of construction such as: liquid-in-glass thermometers; Bourdon tube thermometers; expansion thermometers; resistance thermometers; thermocouple pyrometers; radiation pyrometers; optical pyrometers; fusion pyrometers. The application, principle of operation, usual range and probable accuracy (as given in Mechanical Engineering Laboratory Practice by Shoop and Tuve) are shown by the accompanying table.

Liquid-in-glass thermometers depend upon the expansion or contraction of a liquid sealed in a glass tube, mercury, alcohol and propane being some of the liquids used. Mercury is the most common, the design and construction of the instruments being too familiar to need detailed description. Figure 1 shows four designs: A the common etched glass type; B the same type armored to give added protection; C and D, commercial types for permanent installations. Ordinary lead glass thermometers are good for a maximum temperature of about 550 deg. F. By using special glass and filling the space above the mercury with nitrogen the range can be increased to about 1000 deg. F. and with fused quartz, with nitrogen or CO_2 gas, to about 1500 deg. F. These latter are, however, expensive and intended primarily for the laboratory service.

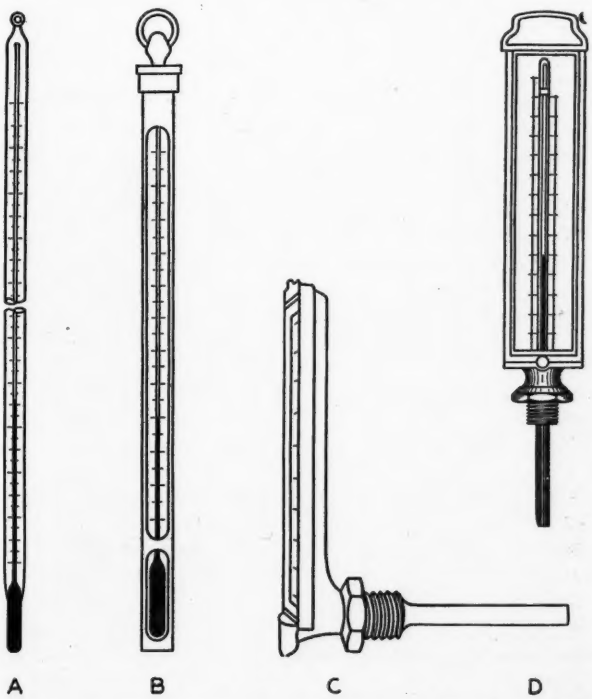


Fig. 1. Various types of mercury thermometers in common use

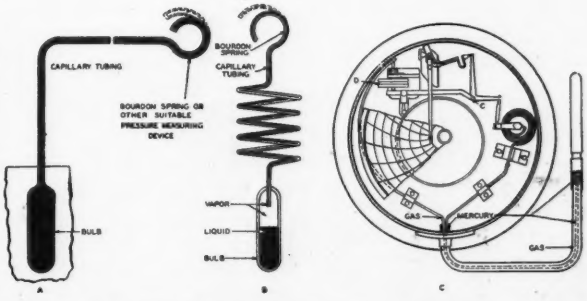


Fig. 2. Pressure type thermometers. A. Class I (liquid filled) and Class III (gas filled) B. Class II (vapor pressure) C. A mercury filled pressure type thermometer with a device to compensate for temperature fluctuations along the connecting tube

Liquid-in-glass thermometers are indicating instruments, although the expansion of liquid, gases and vapors is used in recording instruments using the Bourdon tube. This type of thermometer is designated as Class I, Class II or Class III depending upon whether they are filled with liquid, vapor or gas. The fundamental construction is shown by Figs. 2A and 2B. Expansion of the material in the bulb and tube creates a pressure proportional to the temperature and this pressure is indicated or recorded by one of the several types of Bourdon tube gages described in the preceding article.

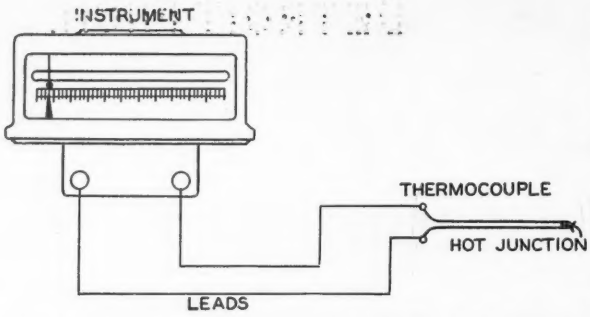


Fig. 3. Arrangement of a thermocouple and indicating instrument

Mercury and alcohol are used in the Class I instruments in which both the bulb and tube are completely filled with liquid. Unless the recording or indicating mechanism is compensated for temperature variations along the length of the tube, the length of the usual capillary tube is limited to about 25 ft. Figure 2C shows a recording type, using a special Bourdon spring, mercury and a compensating device to take care of temperature variations between the bulb and gage mechanism. The pressure of the gas filled space along the tube acts on the spring D to automatically shift the fulcrum C. One type of capillary tubing, made exceedingly accurate and with an alloy core, successfully takes care of temperature fluctuations over line lengths of 100 ft. and over without further compensating devices.

Class III thermometers differ from Class I only in that gas is used instead of liquid, nitrogen, the most common having a working range of between –60 and 1000 deg. F. In the Class II thermometers the bulb is partially filled with liquid and the balance of the system with saturated vapor. This of course obviates the necessity for compensating devices provided the bulb is below the recorder and the tubing free from liquid. Alcohol, benzine, water, toluene, aniline, sulphur dioxide and ether are some of the liquids used.

Solid type expansion thermometers are also used, usually making use of the expansion of two dissimilar metals. The expansion is proportional to the temperature and is used to actuate a pointer through a suitable gear train. The range is from 0 to 1000 deg. F.

The electrical resistance thermometer is sensitive and accurate over a range from about –300 to 1800 deg. F. It is used as an international standard and consists essentially of a small coil of wire. The resistance of this wire changes with the temperature and by suitable calibration an accurate thermometer can be made. The indicating instrument may be a deflection galvanometer (or millivoltmeter to be described in a later article), a potentiometer (to be described in connection with thermocouples) or a resistance bridge. A simple form of Wheatstone bridge for this purpose is shown in the schematic diagram, Fig. 6.

Complete, the meter consists of three elements: the resistance bulb BA; an indicating instrument; and the Wheatstone bridge. The bridge has a battery, rheostat and four resistance elements, D and E which are equal, P which is equal to the resistance of the bulb at its highest temperature and X equal to the resistance of the bulb at the lowest temperature reading. The double pole, double throw switch simply substitutes the resistance X for the bulb in the instrument circuit.

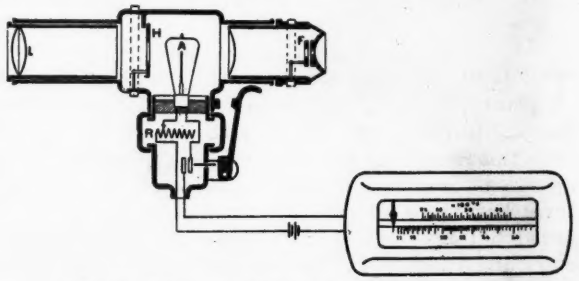


Fig. 5. Schematic view of an optical pyrometer

Before use, the switch is thrown to the right and the rheostat adjusted until the indicator deflector is at the lowest reading of the scale. The switch is then thrown to the right and the thermometer is ready for use. The diagram shown is for what is known as a 3 wire bulb, which eliminates the necessity for calibration in the field and equalizing of the leads. Two wire bulbs are sometimes preferred due to the saving of wire with long leads but this requires special provision to adjust the lead resistance to a fixed value.

Still simpler is the thermocouple, an elementary form of which is shown by Fig. 3. The thermocouple consists of two dissimilar wires with the ends joined. This junction acts as a small battery, the voltage generated depending upon the metals used and the temperature difference between the cold and hot ends. Thermocouples may therefore be used as thermometers by measuring the voltage produced. This is usually done either with a millivoltmeter or a potentiometer. The millivoltmeter construction will be found with the electrical instruments while a simple diagrammatic potentiometer circuit is shown by Fig. 4.

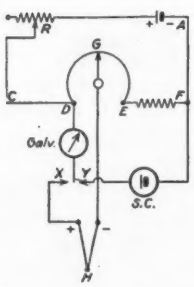


Fig. 4. Fundamental potentiometer circuit

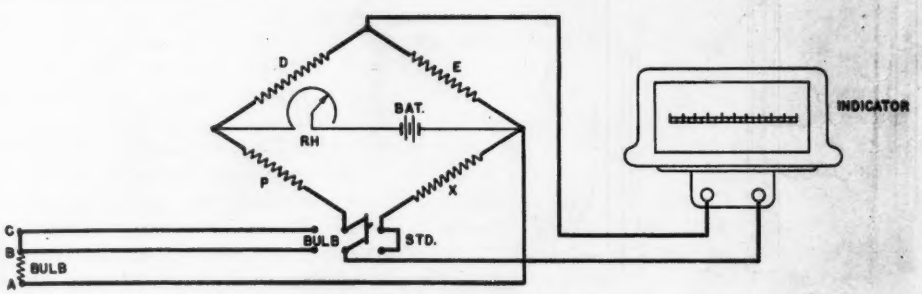


Fig. 6. Wheatstone bridge circuit as used with a resistance theremometer for the accurate measurement of temperatures over a wide range

With the switch thrown to Y, the diagram consists of two circuits, one with the galvanometer and standard cell SC, the other with the resistance R and the battery A. A rheostat G and resistance F are common to both circuits. The circuits are standardized by adjusting the resistance R so that there is no deflection of the galvanometer. The switch is then thrown to X and the voltage generated by the thermocouple H balanced against the standardized voltage of the battery X at D by means of the rheostat G. When this balance is obtained there will be no deflection of the galvanometer. By fitting a suitably calibrated scale to the rheostat G temperatures may be read directly. In earlier thermocouples the cold junction was either maintained at a uniform temperature by burying it in the earth or in a jar of cracked ice. Modern instruments have automatic compensators.

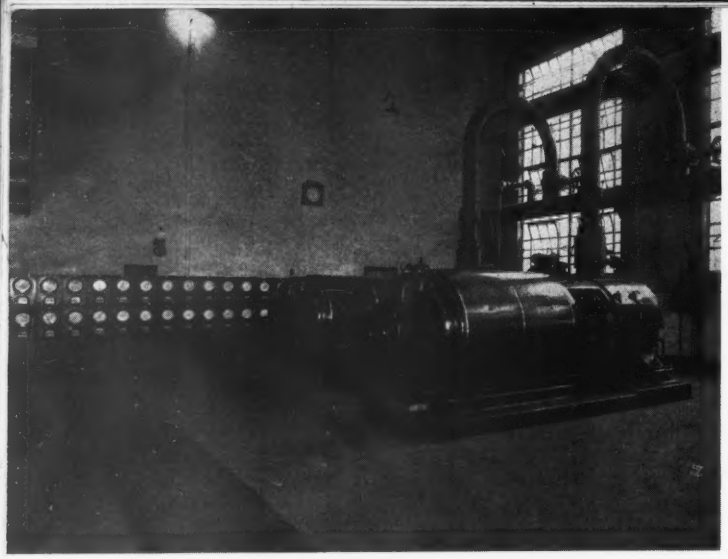
Radiation pyrometers are really thermocouples mounted in a tube behind a lens so that the radiant heat energy is focused on it and the voltage generated by the thermocouple measured as explained previously. The lower temperature range of this type of instrument is about 1000 deg. F. and the upper limit above anything encountered in the power plant.

Somewhat similar is the optical pyrometer, one type of which is shown by Fig. 5. The intensity of the flame or body being measured is compared with the filament A which is varied in temperature (or color), until it is invisible against the object whose temperature is being measured. The temperature is then read in the calibrated scale of the galvanometer.

Pyrometer cones are often used to determine furnace temperatures especially in laboratory practice. They consist of mixtures of minerals and prepared glass, variation in the mixture producing cones of definite melting points.

Limitations and applications of various types of temperature measuring instruments for laboratory and plant use

Common name	Type or subclass	Principle of operation	Usual ranges of temperature measured, deg. fahr.	Special advantages	Typical engineering and industrial uses	Probable accuracy (deg. fahr. plus or minus)
Mercury thermometer	Common	Volumetric expansion of a liquid in a vacuum	−35 to 600	Inexpensive; easy to handle; easy to read; accurate	Water temperatures in power-plant test work	Depends on design
Mercury thermometer	Gas-filled	Volumetric expansion of a liquid under pressure	0 to 1000	Wide range; simple; inexpensive; accurate	Steam temperatures; flash point of oils; flue-gas temperatures	Depends on design
Expansion thermometer	Liquid, gas or vapor filled, pressure-gage type	Pressure change of liquid, gas or vapor confined in constant volume	50 to 1000	Rugged; recorder or indicator may be placed at a distance (to 200 ft.)	Flue-gas, steam, and water temperatures in power plants; core-oven, baking-oven, and enameling-oven temperatures	2 to 10
Electrical-resistance thermometer	.....	Change of electrical resistance of a metal with change in temperature	−300 to 1800	Accurate; sensitive; one indicator for many temperatures; distant reading	Temperatures within stored materials subject to heating, as coal, grain, etc.; laboratory and experimental work	0.1 to 0.5
Thermocouple pyrometer	Base-metal couple and millivoltmeter indicator	Measurement of thermocouple e.m.f. by millivoltmeter	To 200 with Bi-Sb; To 900 with Cu-constantan; To 1500 with iron-constantan; To 1600 with nichrome-constantan; To 2200 with chromel-alumel; To 2200 with nichrome-alumel	Rugged; well adapted to distant reading; easily made recording; one indicator for many couples	Temperatures in furnaces of all kinds, up to 2200 deg. fahr.; heat-treating temperatures; temperatures in glass, ceramic, and oil-refining industries; temperatures in boiler settings and flues; exhaust temperatures of gas and oil engines	3 to 20
Thermocouple pyrometer	Base-metal couple and potentiometer indicator	Thermocouple e.m.f. balanced against known battery e.m.f.		More accurate than millivoltmeter type		0.5 to 10
Thermocouple pyrometer	Noble-metal couple and potentiometer indicator	Thermocouple e.m.f. balanced against known battery e.m.f.	To 2600 with platinum-rhodium	High range; temperature-e.m.f. curve does not vary with age of couple	High-temperature or precision work in laboratory	0.5 to 5
Radiation pyrometer	.....	Total radiation from hot body heats thermocouple placed in focus of concave mirror	From red heat to maximum temperatures encountered in industrial work	High and wide temperature range; can be made recording	Temperatures of furnace walls and interiors, large ingots; molten metals, glass	10 to 50 under black-body conditions
Optical pyrometer	.....	Sighting tube with disappearing filament or divided field compares intensity of monochromatic radiation from hot body with that of standard	From red heat to maximum temperatures encountered in industrial work	Easy to use; high and wide temperature range; instrument may be "sighted" on small hot body or body in motion	Temperatures of furnaces, ingots, forgings, steel plates and rails, ceramic kilns, molten metals	10 to 35 under black-body conditions
Fusion pyrometer	Pyrometric cones	Series of fusible cones with melting points about 50 deg. apart	1000 to 3600	Simple; inexpensive; wide range	Ceramic kilns	20 to 50



Flowmeters in the Penick & Ford Plant at Cedar Rapids, Ia.

(Courtesy, Republic Flow Meters Co.)

Quantity Measurement of Solids *and* Liquids

Weighing Formerly Considered the Only Accurate Method of Fluid Measurement Now Largely Superseded by Accurate Flow Meters

QUANTITY MEASUREMENTS, that is the determination of the amounts of various solids and fuels used in the power plant, are extremely important as it is from these measurements that the efficiency of the plant and of the individual machines is determined. As a rule weight measurements, pounds of coal burned, pounds of water evaporated, or pounds of steam used, are the most important, although with water, gas and air, volumetric units such as gallons or cubic feet are in common use. These volumetric units are fundamentally weight measurements, however, and must be corrected to standard pressure and temperature conditions to have a definite value in accurate engineering work.

Platform scales in various forms are well suited to most weighing operations and when new are quite accurate and sensitive so that they may be considered the simplest and most fundamental device for practical quantity measurements. Scales of this type are usually given hard service and little care so that the knife edge is often dulled or damaged and the adjustment changed. Scales should always be calibrated with standard weights and adjusted before being used for important work.

When a wheelbarrow of coal is weighed on a scale and the weight of the empty barrow subtracted, there is no question as to the amount of coal used. If, however, the wheelbarrow is filled full and the weight estimated from past weighings there may be considerable question as to the actual amount of coal even though the shape of the barrow may be such that the same volume may be obtained each time. This is the first fundamental division in measuring equipment; weighing and volumetric devices.

Coal weights may be estimated from the volume of a pile, a car or bunker and although this can be done with considerable accuracy after calibration, it is obviously not a very reliable method. Car weighings are quite reliable but the quantities involved are too large to be of much immediate use in checking performance. The most simple arrangement is a platform scale large enough to weigh a wheelbarrow or car full as used. In hand fired plants this may be practical but is obviously not practical for modern plants with coal handling equipment.

To meet this need the weigh larry was developed by combining a suitable and accurate scale with a hand or motor propelled larry for charging stoker hop-

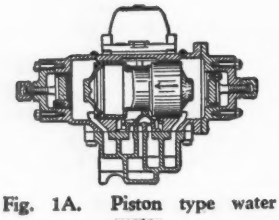


Fig. 1A. Piston type water meter

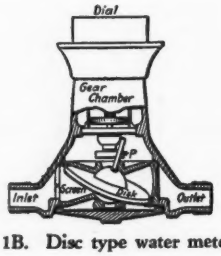


Fig. 1B. Disc type water meter

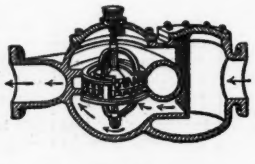


Fig. 1C. Turbine meter for large flows

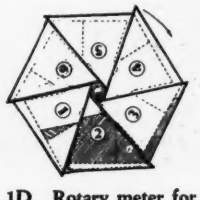


Fig. 1D. Rotary meter for condensate

pers. Figure 2 shows a fireman weighing the coal that he will soon feed direct from the larry to the stoker hopper. A number of other methods are also used, for instance a vane turned in a pipe or spout by coal flowing through it, by measuring the gate opening and speed of a chain grate stoker or the speed and plunger stroke of an underfeed stoker. These are all volumetric measurements and subject to the limitations of this method for the measurements of solids but are sufficiently accurate to give relative readings.

In pulverized coal plants the coal is usually metered before the pulverizer by measuring devices, sometimes of the volumetric type but more often of the weighing type, that is the fuel is weighed out automatically and dumped in batches of say 400 lb. As with stokers the speed of certain parts, for instance the feeder screw, may be used as an indication of the pulverized coal feed direct to the boiler. Where belt conveyors are used special scales can be installed to weigh automatically the coal as it passes. This type of scale reads the rate of flow in pounds per hour and automatically integrates this rate so as to give the coal flow in pounds or tons.

This difference represents the second important division in measurement; quantity meters which read the absolute quantity as pounds or cubic feet irrespective of time and rate of flow meters which consider only the instaneous quantity as pounds per hour or cubic feet per hour. An automobile speedometer is a combination of both quantity and rate instruments. One set of figures, a simple counter, registers the actual miles traveled, say 100 mi., regardless of whether this distance was traveled in two hours, or two weeks or two months. The other instrument indicates the rate of travel at any instant, in that case, the distance in miles that the car would travel in an hour if the speed did not change.

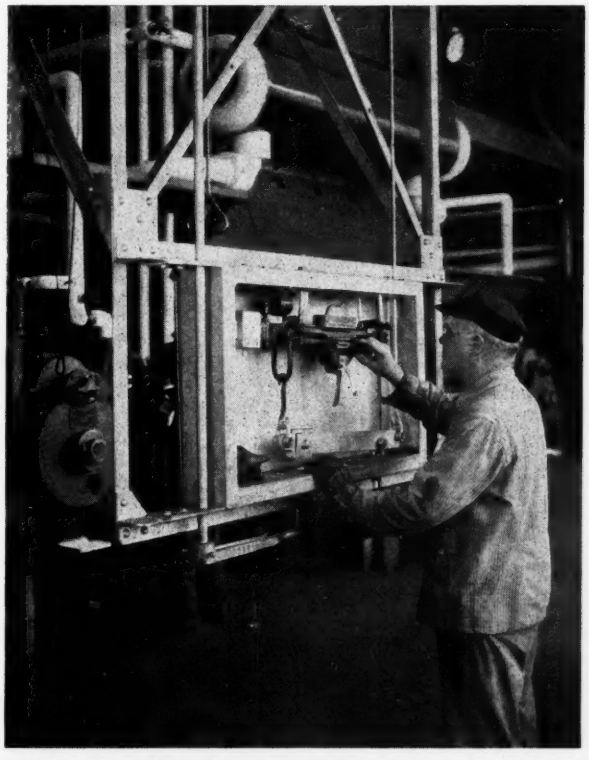


Fig. 2. One of the first steps in efficient operation, weighing the fuel

Table. Classification of fluid meters as adopted by the A.S.M.E.

Quantity Meters

Division	Class	Type
1. Positive	1.1 Weighing	1.11 Weighers
		1.12 Tilting Traps
	1.2 Volumetric	1.21 Tank
		1.22 Piston
		1.23 Disk
		1.24 Rotary
		1.25 Bellows
		1.26 Wet Drum
2. Inferential	2.1 Current (Kinematic)	2.11 Propeller
		2.12 Anemometer
		2.13 Turbine
		2.14 Helical

Rate of Flow Meters

2.2 Head (Kinetic)	2.21 Venturi
	2.22 Flow nozzle
	2.23 Thin-plate orifice
	2.24 Pitot
	2.25 Centrifugal
	2.26 Friction
2.3 Area (Geometric)	2.31 Gate
	2.32 Orifice and plug
	2.33 Cone and disk
	2.34 Cylinder and piston
2.4 Head-area (Weir)	2.41 Rectangular notch
	2.42 Triangular notch
	2.43 Special notch
2.5 Force	2.51 Hydrometric pendulum
	2.52 Vane
2.6 Thermal	2.61 Electric

Meters of Types 1.11 to 2.14 inclusive are quantity meters primarily. Meters of Types 2.21 to 2.61 inclusive are rate of flow meters primarily. When the latter are designed to give total quantity, a time element forms part of the secondary device.

These classifications are perhaps better illustrated by water metering devices. Before the introduction of accurate flow meters, the only way steam could be measured was to condense it and measure it as water. These measurements were considered very important and when extreme accuracy was desired this water was actually weighed on scales. By having two quick emptying tanks of suitable size mounted on scales, the continuous flow could be measured by filling one tank while the other was being weighed and emptied. Automatic dumping devices and counters were sometimes used for this purpose, the ordinary tilt trap being a good illustration of the principle involved. As the water level rises the center of gravity changes until the counterweight is overbalanced and the trap tilts on its supports. If the trap is connected to a counter the counter reading is a measure of the total flow.

As there is a limit to the size of scale and tank that can be used for this service, volumetric measuring tanks have, of necessity, to be used for large flows even though their use involves temperature correction factors. Such a tank must be calibrated. This may be done from measurements but a weighed calibration is preferred. This is done by actually weighing the water used for calibration and recording the depth with each addition, usually by means of a float gage or hook gage. For convenience, the calibration is shown by means of curves.

A tank of course is not the only volumetric type

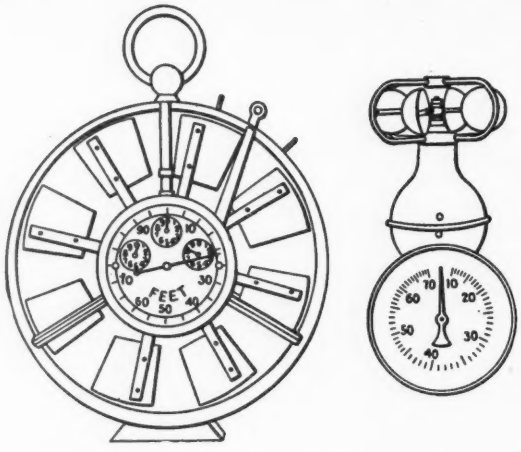


Fig. 3. Two types of anemometers; (left) a type that measures the total distance and which must be used with a stop watch to determine the average velocity and (right) a type that indicates the instantaneous velocity direct

meter. An ordinary reciprocating pump is a crude positive displacement volumetric meter as each stroke displaces a certain amount of water. Unfortunately, however, variable lengths of stroke and indeterminate and variable slip destroys the accuracy. The same principle is, however, used in the so-called piston meter shown by Fig. 1A. Pressure of the water is used to operate duplex pistons which in turn move internal valves which operate the meter in much the same way as a duplex steam pump. An attachment to the counting mechanism records the flow in gallons or cubic feet.

The disc meter shown by Fig. 1B is also a positive displacement meter which operates somewhat like a rotary pump. The measuring chamber is divided into two equal parts by the top shaped disc arranged so that there is always an unbalanced water pressure which keeps the disc moving and empties first one and then the other chamber. The rotary motion of the pin P is transferred to the counting mechanism by the gear train. These meters are made for oil, gasoline, hot and cold water, although not interchangeably as the composition of the disc must be suited to the service. Cost of these meters is roughly proportional to the capacity, making it possible to meter the small lines economically. The maximum capacities run around 1000 g.p.m. for cold water and 200 g.p.m. for hot water.

Then there is the turbine meter made in different forms, one of which is shown by Fig. 1C which is in the form of a small water wheel. This type is used primarily for measuring large flows. Another type makes use of the vortex effect of the water directed through the meter helically to actuate a paddle wheel

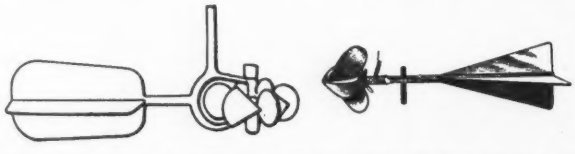


Fig. 4. Two types of current meters. The usual method is to have the rotating part make an electrical contact which operates an electrical counter located in some convenient place above the water level

and counter-mechanism. For hot water and condensate measurement the rotary meter of the type shown by Fig. 1D is widely used. The metering element is caused to rotate by the shifting center of gravity as the various compartments fill one after the other. In the illustration compartment 1 is almost empty, compartment 2 is almost full and will begin to discharge as soon as the flow is shifted to compartment 3.

With the exception of the turbine meter, all the liquid meters mentioned above are of the positive type in which the fluid flows through in successive isolated quantities, that is the quantity meters as mentioned above, a larger group of fluid meters most of which come in the rate of flow class are of the type known as inferential as contrasted to positive. That is, the fluid flows through continuously and the quantity is "inferred" or estimated from some particular indication such as the height over a weir or the pressure drop across an orifice. As a rule this type of meter requires

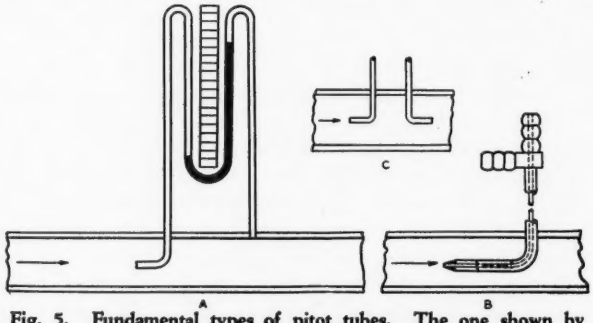


Fig. 5. Fundamental types of pitot tubes. The one shown by B is the A.S.H. & V.E. standard type

careful calibration or experimental determinations of the relationship between the indication used and the flow.

Of these inferential meters, the current or velocity meters are perhaps the closest to the positive meters and are widely used. The anemometer, Figs. 3A and B are of this type and are used primarily for determining air velocities. When used for measuring water velocities they are called current meters, several forms being shown by Fig. 4. They are in wide use in hydro plants and in the hands of experienced operators are quite accurate. This method is inferential because it is impossible to obtain the velocity of all the material flowing, so that the average velocity is estimated or inferred from a number of carefully selected points in the section.

The pitot tube, although classed as a head or kinetic meter, is closely related to the current meter because it is used to measure the velocity of the fluid and the flow is calculated from this velocity. Pitot tubes are commonly used in pipes or ducts and a traverse made across one or two diameters for the purpose of finding the average velocity.

A number of different types are shown by Fig. 5. With no flow, the pressure in both legs of the manometer is equal to the static pressure. As the flow or velocity increases the tube pointed upstream reads the static pressure plus the velocity pressure, which is proportional to the square of the velocity. If the other tube is properly installed it is unaffected by the velocity and continues to read the static pressure so that

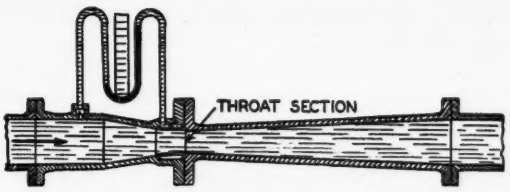


Fig. 6. Typical section of a Venturi tube

the difference in pressure between the static pressure and total pressure tubes as read by the manometer is a measurement of the velocity in the pipe. For accurate pitot tube measurements it is necessary to have reasonably steady flow and the tube should be preceded by 10 to 20 dia. of straight pipe.

Velocity traverses can be made to determine the average velocity after which the tube may be mounted stationary at some point in the pipe, either 0.12 to 0.15 dia. from the side where average velocities exist or at the center. For normal turbulent flow the average flow is about 85 per cent of that at the center. This varies with the size of the pipe, location of bends and viscosity of the fluid and should be determined experimentally for each case. An impact tube, used for air compressor and blower tests, differs from the pitot tube in that the static opening is eliminated and the impact opening mounted in front of a well rounded nozzle. The nozzle is also used for water measurements, the flow being proportional to the area of the nozzle and the water pressure at the nozzle.

Closely related to the pitot tube are other forms of head meters, so-called because the flow creates a difference in pressure or head through the primary meter device. This head is proportional to the velocity and density of the fluid and is a measure of the flow. The Venturi tube, shown by Fig. 6, is one of the oldest accurate flow meters. The increase in velocity through the throat causes a drop in pressure which is indicated on the manometer. The flow nozzle and flat plate orifice, Fig. 7, are also used in the same way. The pressure taps are used in different positions with reference to the orifice or nozzle, ranging from locations immediately adjacent to the orifice to several pipe diameters away. Pressure changes begin about 1 pipe diameter ahead of the orifice and are again steady about 4 to 4.5 pipe diameters below the orifice. As the flow with this type of meter is proportional to the square of the head or pressure differential shown by the manometer, scales and charts made to show the flow direct have a nonuniform or squared scale unless this is compensated for by the secondary or recording element as is sometimes done.

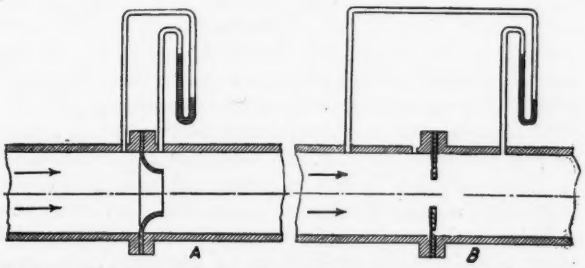


Fig. 7. The flow nozzle (left) and flat plate orifice (right) used as flow meters

By suitable calibration any bend or obstruction that causes a small pressure drop may be used as a primary metering device. In hydro plants it is customary to install pressure taps in penstocks or scroll cases. After calibrations these taps are used as a flow indicator. Calibration, dealing with such large quantities of water, is usually done by the pressure-time, salt velocity or current meter methods.

The last has been mentioned above. In the pressure-time method, steady flow is established and a valve is then closed. Records of the pressure fluctuations in the penstock are then made photographically and the flow calculated from these. In the salt velocity method a solution of salt is injected and the time it takes to travel a known distance is determined by suitably placed electrodes. Flow is calculated from the velocity and pipe size.

Flow nozzles and Venturi tubes are made symmetrical or concentric with the pipe but flat plate orifices are sometimes made in segmental or eccentric form to meet various conditions of service for gases or liquids. In fact, the orifice is sometimes made with a variable area, either as a rapid method of changing the orifice for the purposes of taking care of wide variations in flow through the same pipe as Fig. 8A or for a different type of meter using a constant head. Most meters use a fixed orifice and determine the flow through the variation in head. Other meters, however, use a constant head or pressure differential and vary the orifice opening to maintain the given head. The opening of the orifice is then used as an indication of the flow.

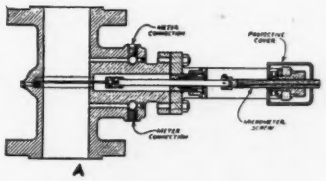


Fig. 8A. One type of variable area flow meter orifice

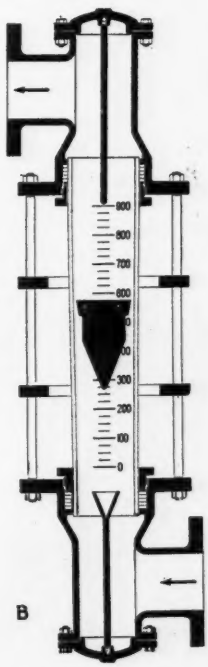


Fig. 8B. A variable area meter in which the rotating indicator moves in a conical graduated tube

Such a meter is classed as an area meter, other meters of this type being shown by Figs. 8B and 8C. The second one shows a meter with a cone operating vertically in a circular ring or orifice. Gravity supplies the constant head or pressure differential and as the flow increases the cone lifts up its height giving indication of the flow. In Fig. 8B, the meter body is of conical shape with the small end down. At no flow the rotor rests on the bottom completely filling the body of the meter cone. As the flow increases the rotor is forced up until the area between it and the meter body is sufficient to pass the required flow. The height of this rotor is an indication of the flow.

In Fig. 8D a different principle is used, the orifice acting as an obstruction and causing a portion of the flow to pass through the side passage where it acts on a small rotor. Movement of this rotor is communicated to a counter through the vertical shaft and a magnetic drive. A definite portion of the main stream is metered and serves as a measure of the total.

Weirs form a very old and important group of water measuring devices, used in the power plant principally as boiler feed water meters. For various purposes different shaped notches are used, the V notch being used for boiler feed service due primarily to the accuracy obtained over a wide range of flows. The weir is a combination area-head meter, both the area through which the water flows and the head causing the flow varying at the same time. The head of water flowing over a weir is measured in a number of ways, the float gage being used with indicating and recording mechanisms.

There are, of course, other types of meters which might be used, a check valve, for instance, is a crude sort of meter, as its movement from normally closed position is an indication of the flow. The only other type of commercial importance, however, is the thermal meter used for gas and air measurements. In this meter an input of heat, in the form of electricity,

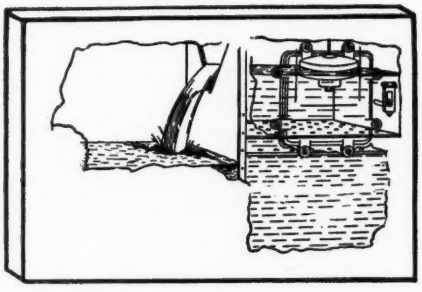


Fig. 9. V-Notch boiler feed meter

results in a temperature rise of the gas flowing through the meter. From the temperature rise and the specific heat of the gas the flow may be calculated. Or the temperature rise may be kept constant and the electrical input used as a measure of the flow.

All types of meters must, of course, be considered in two parts; the primary element that is acted upon directly by the fluid or material being measured and the secondary element that is used to translate this effect into units measured. The first or primary elements are comparatively few and the principles upon which they operate relatively simple and easily classified as shown by the table in the early part of this article. The secondary devices may be varied indefinitely, some of the more common will be covered in a later article dealing with recording and telemetering instruments. Many of the simpler meters use only a simple counter as a secondary element. In the modern plant the total quantities given by such a counter is not always sufficient, however, as evidenced by the large number of indicating and recording meters used.

The majority of these present day fluid meters are rate of flow meters, that is, the indicator and recorder shows and records the flow at any instant. In order to obtain the total flow over a period of time, the flow must be integrated, that is, the flows for each instant must be added automatically and the total recorded on a suitable counter. In effect these integrators compute the area under the recorder curve and translate the area found into the desired units. In the early days these integrators were not available and it was necessary to calculate the total flow from the charts by means of a planimeter and suitable constants. It can thus be seen that the integrating mechanism of a rate of flow meter is far from the simple counter used as a totalizer on quantity meters which isolate and measure a definite weight or volume with each operation, the definite weight or volume with each operation, the total number of operations being a measure of the total flow.

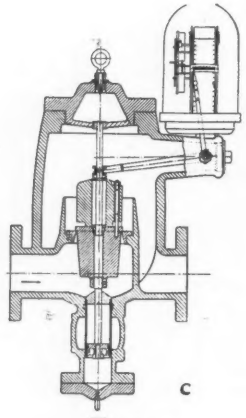


Fig. 8C. A variable area meter in which a cone shaped plug moves up and down in a fixed seat or ring

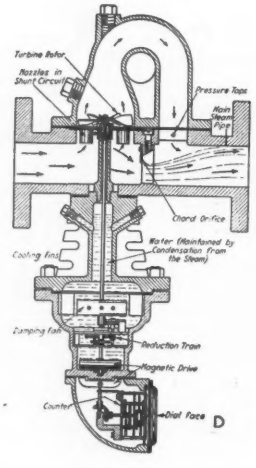


Fig. 8D. A meter in which a portion of the total flow is forced through a meter rotor by a chord orifice in the main line

Tachometers *for* Speed Measurement

SPEED MEASUREMENTS and observations may be made in a number of different ways, the most elementary method being to count the number of revolutions in a certain time interval. For this purpose hand tachometers of the type shown by Fig. 1 are available for use in connection with a timepiece, preferably a stop watch. The top counter consists of a moving hand or indicator dial turned from a worm gear on the shaft. The lower counter, or cyclometer, has a straight reading dial operated directly from the shaft.

Both of these are fundamentally hand instruments and can be fitted with different types of steel or rubber tips to fit different types of shafts. They can be used accurately up to around 2000 r.p.m. but for speeds of 600 r.p.m. and over should have a positive connection to the shaft to prevent slipping. When used in connection with a stop watch the speed in revolutions per minute must be calculated by dividing the total revolutions by the total time in minutes. In the tachoscope the revolution counter and stop watch are combined in a single instrument arranged to operate simultaneously. By averaging the revolutions over short periods of time by a balance wheel and cam arrangement, revolutions per minute can be read directly on a dial. These instruments are usually fitted with special tips and scales so that lineal speeds or angular speeds can be measured and can be made for speeds as high as 30,000 r.p.m.

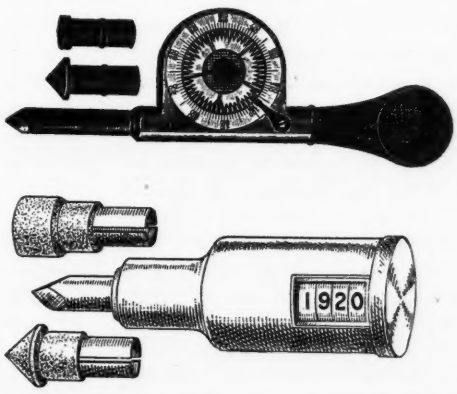
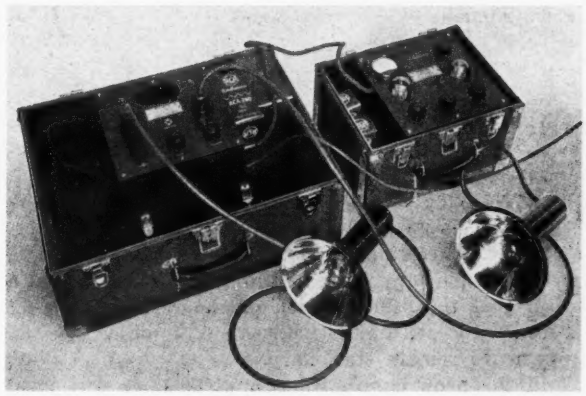


Fig. 1. Above hand revolution counter operated through a worm gear on the shaft and below a hand revolution counter of the cyclometer type

A tachometer proper indicates the speeds directly and continuously without direct reference to the time element. They are made in different types, one the flyball tachometer being fundamentally the same as a flyball governor. For each speed the spring loaded flyballs assume a definite position which is indicated by a pointer on a calibrated scale.



Neon lamp stroboscope for studying rapidly moving machinery

The liquid tachometer is fundamentally a small centrifugal pump, the speed indications being shown by the height to which the liquid is pumped in a calibrated scale or manometer. A pneumatic tachometer operates on the same principle, one form consisting of a rotating tube pivoted in the center. As it rotates a suction is produced and this suction registered on a suitable indicator or recorder (an inverted, oil scales bell such as used in draft gages) with a suitably calibrated scale being a measure of the speed. Force-drag tachometers depending upon the drag produced by rotating element which transmits a force from it to another movable part or indicator is used extensively in automobile speedometers but little in power plant work.

Two forms of electric tachometers are in wide use, the electromagnetic type consisting of a direct cur-

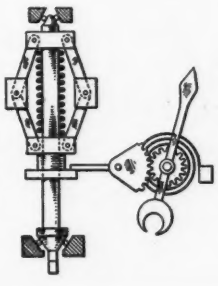


Fig. 2A. Elementary type of flyball tachometer

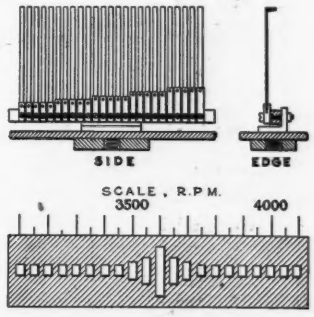


Fig. 2B. Vibration tachometer using steel reeds

rent generator with a suitable voltmeter indicator or recorder and an ordinary frequency meter calibrated to read speed instead of frequency. The generator used in the first type is of the permanent magnet type so that the voltage is a function of the speed. The principle of the electrical type of frequency meter or meters is described in the section on electrical instruments and should not be confused with the vibration or reed type tachometer shown by Fig. 2B. This type of tachometer employs no electrical connections but depends upon the mechanical vibration of the rotating member. Its most common use is on a speed indicator or turbines in the range of from about 800 to 12,500 r.p.m.

Stroboscope

The stroboscope is a device which has been used for many years but which achieved no particular commercial prominence until the development of the neon lamp. In principle the stroboscope depends upon the persistance of vision when an object is viewed intermittently. Mechanical models usually consist of a revolving slot or perforated disc driven at such a speed that the same portion of the revolving object is seen with each light flash so that the object viewed appears to remain stationary.

In the neon lamp stroboscope the lamp is turned on and off each fraction of a second. By adjusting the speed of the flash the object viewed may be made to stand still or move slowly in either direction. One of the interesting applications of the stroboscope which indicates its commercial possibilities is in the timing of watches, the properly timed balance wheel appearing stationary when viewed under an accurately timed stroboscope.

Naturally the drive from the machine to the

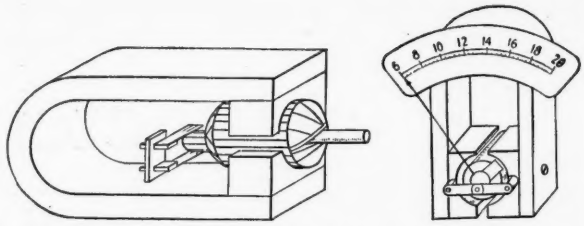


Fig. 3. Elementary form of an electromagnetic tachometer

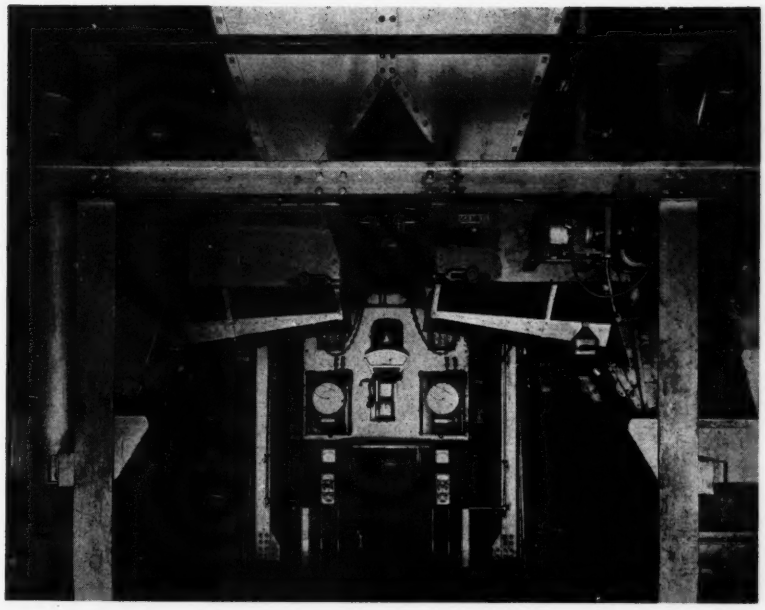
tachometer is of extreme importance as slip introduces an indeterminate error. Several positive drives are recommended by the A.S.M.E. Test Code. The first is a gear or chain drive, the second a flexible shaft in a suitable housing and the third a pin threaded into the end of the revolving shaft with a slotted metal sleeve as a driving link between the shaft and tachometer. This latter method may be used with or without a universal joint between the two. Pressing the tachometer shaft into contact with the rotary shaft or the use of belt or friction drives is not considered a positive drive and although sometimes necessary, one of the three positive drives should be used whenever practical.

Tachometer Classification

In the accompanying table (taken from the A.S.M.E. Test Code) the operating principles of the various types of tachometers are listed. Naturally the fundamental principles covered are incorporated in a score of commercial designs which differ greatly in detail and which are made to meet definite needs. Instruments are so highly developed today that practically any type may be adapted for indicating or recording service.

Operating principles of various types of tachometers

Type of tachometer	Principle of operation		Local or distant reading	Accuracy affected by	
	Force produced by	Force measured by		Operating conditions	Changes in tachometer mechanism
Centrifugal fly-ball and tilting ring	Rotating weight	Spring tension	Local	Position, temperature slightly	Lubrication, spring tension wear at joints
Centrifugal liquid pump	Centrifugal pump	Head of liquid	Local	Position, non-uniform temperature of the instrument	Amount of liquid
Centrifugal air	Centrifugal tube	Air pressure	Distant	Temperature and atmospheric pressure	Sensitiveness of pressure indicator or recorder, leakage in connecting lines
Hydraulic pump	Pump	Oil pressure	Distant	Oil temperature	Change in spring tension
Magnetic drag	Rotating magnet	Spring tension	Local	Temperature	Loss of magnetism, change in spring tension or pivot friction
Liquid drag	Rotating cup of mercury	Spring tension	Local	Slight variation of viscosity of mercury with temperature	Change in spring tension, clearance, and friction
Air drag	Rotating cup in air	Spring tension	Local	Temperature	Change in spring tension, clearance, and friction
Chronometric	Direct drive motion	In gear for an exact period of time	Local	Accuracy of timing device, temperature	Slip or failure of ratchet device
Electromagnetic	Magneto	Voltmeter	Distant	Temperature and iron in proximity to generator and line resistance	Loss of magnetism of permanent magnets, brush resistance
Frequency-meter	Magnetic induction	Torque on disk	Distant		
Vibration	Vibrations from running machine	Vibrating reed	Local	Vibration from other source, temperature	Change in reed structure in time by crystallization, etc.



Instrument panel in the municipal electric plant at Chambersburg, Pa. A coal bin is provided for supplying each pair of boilers, these bins have bifurcated bottoms from which the coal flows through automatic scales that discharge directly into the hoppers of the pulverizers as shown. Against the wall behind these pulverizers the instrument boards are set up, each panel board being equipped with two multiple pointer draft gages. An indicating and recording flow-meter is provided for each boiler. The indicating and recording CO_2 meter is set and connected so that it can be used to indicate the CO_2 in either one of the two boilers which the instrument panel serves. On the panel below each flow meter an ammeter and integrating watt-hour-meter is provided to show the current input and energy consumption for each of the pulverizer motors. (Photo courtesy Albert C. Wood)

Boiler Room Instruments for Better Operation

Operators Must Have Reliable Guides If Plant Efficiency Is to Be Maintained

SUCCESSFUL AND EFFECTIVE power plant operation demands, among other things, the efficient utilization of the fuel. This means that the fuel must be completely burned so as to release the chemical energy in the form of heat and that this heat must be absorbed as completely as the available boiler equipment will permit.

Chemical analysis of the resulting flue gas enables the engineer or fireman to judge the completeness of combustion while the temperature of the flue gas is a guide to the effectiveness with which the heat is being absorbed. A complete chemical analysis sounds rather formidable but as a matter of fact it can be accomplished very easily by means of a conventional Orsat.

This equipment, shown more or less diagrammatically by Fig. 1, is ordinarily equipped to determine the CO_2, CO and O_2 of the gases to be analyzed. Sometimes a fourth pipette is added for the determination of H. The analysis is fundamentally volumetric. A definite sample, usually 100 c.c., is taken and passed through chemicals which absorb the various component gases. After each absorption the volume of the remaining gas is measured under the same pressure, the decrease in volume after each absorption giving a direct volume percentage of the gas absorbed.

The essential features of the Orsat are shown in Fig. 1 though commercial types are more conveniently arranged, one being shown in operation in the headpiece of a later article. To obtain a true sample of the gases is quite as important as making the analysis and to determine the proper location of the sample tube sometimes requires considerable preliminary exploration and judgment. Pockets back of dampers and at bends and other locations that are likely to affect the average gas mixture must be avoided.

The gas sample is carried from the sampling pipe in a single tube to the bottle A for the separation of the condensed moisture and tars, past the tee (the tube should be capillary bore) to which the collecting bottle B is connected, through the suction bottle C half filled with water which indicates that the sample is being drawn and the rate, thence to the aspirator which should cause a strong, continuous and uniform rate of gas flow. The collecting bottle B is fitted with a 3-way stopcock.

Vessel D is somewhat larger than B and contains the water used for displacement. It is connected to B by a rubber tubing fitted with a pinchcock for regulating the flow out of and into the bottle B. With this appartus a continuous sample is drawn from the main stream of the gases, a small part of this sample is drawn off continuously for a few minutes or some suitable period, and a portion of this sample is then analyzed in the Orsat.

In operation the bottle I, containing water and connected to the bottom of the burette H, is raised and

lowered, with proper operation of the stopcocks, to draw a measured sample of gas into the burette. This sample is then forced in and out of the first container E, which contains a solution of caustic potash, for the absorption of CO_2. The loss in volume of the gas due to this absorption is measured by means of the burette and recorded as per cent CO_2. The remaining gas is then passed into the second container F, where the oxygen is absorbed by a solution of pyrogallic acid and caustic potash. The gas is again measured and the second loss recorded as O_2. Then the CO is absorbed in the third container, G, by ammoniacal solution of cuprous chloride. The final loss in volume is the per cent of CO in the gases. The whole test is performed in a few minutes and the results obtained are sufficiently accurate for commercial purposes.

Absorbants and the method of action are as follows, the order in which they are used being important. Potassium hydroxide (sometimes sodium hydroxide is used) will not absorb N_2, O_2, CO or H_2, but will absorb CO_2 and also SO_2 if it is present in the gas. In the second pipette, the solution of pyrogallic acid and caustic potash will not absorb CO_2, N_2 or H_2 but will absorb oxygen. The alkaline part of the solution will absorb CO_2 or SO_2 so it is important that these be removed previous to the O_2 determination. In the third pipette the ammoniacal copper chloride solution for CO removal will not absorb N_2 or H_2 but does absorb CO_2, SO_2 and O_2 so it must follow the other two. Usually the gas remaining after the three absorptions is considered N_2 unless a hydrogen determination is made. This can be done with palladium foil which has the property of absorbing H in large amounts at ordinary temperatures but does not absorb other gases.

With complete combustion, the flue gases would contain no combustible gases, although the most likely one to exist is carbon monoxide. Yet for practical reasons an over supply of air is used resulting in an analysis which is lower than the theoretical in percentage of carbon dioxide and with some oxygen. Again the gases may show incomplete combustion and at the same time an excess of air that is some oxygen is present. This may be caused by the gases being chilled before they have had time to burn, due to low setting or stratification, or by insufficient combustion of air in the furnace accompanied by leaks in the setting beyond the combustion zone.

For perfect combustion there must be enough air to supply the oxygen for completely burning the carbon, hydrogen and sulphur in the fuel, but no more. Practically, this is impossible as it has been found necessary to provide some excess air though this is being reduced gradually as combustion processes are perfected. Carbon being by far the most important combustible element in fuel, the most important among the flue gases is the CO_2 and once a standard percentage for CO_2 has been established for a given setting and fuel, it is only necessary to maintain this standard to ensure best results.

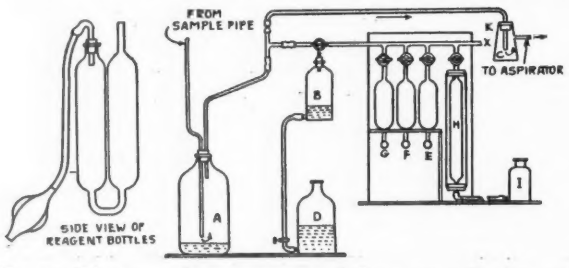


Fig. 1. Diagrammatic arrangement of Orsat gas collecting and analyzing equipment

When this standard cannot be maintained the flue gases should be tested also for O_2 and CO, an examination of which should point to reasons for failure to maintain the proper CO_2. These determinations are usually made by means of an Orsat apparatus which has become standard for spot sampling.

As the CO_2 is the principal index to good combustion, the practical guide to combustion conditions is the CO_2 meter which is made in a variety of models, either indicating or recording. Some of these meters depend upon the absorption of CO_2 in caustic solutions after the sample has been obtained by means of an automatic aspirator, usually steam, water, air or motor operated. After absorption the CO_2 indication may be a direct volume measurement under constant pressure, for instance, by means of a sealed bell, or it may be a pressure measurement under constant volume. One instrument of this type uses two similar orifices in series with the absorption material between. The pressure in front of the second orifice will, of course, vary with the percentage of total gas flue absorbed in the CO_2 absorber and this pressure difference is a measure of the CO_2.

Electrical methods are also widely used, one method utilizing the known difference in thermal conductivity of CO_2 and air. This method consists of passing streams of flue gas and air through special chambers equipped with heated platinum wires. These wires are arranged in the form of a wheatstone bridge and the variation of heat radiation from the wires with different CO_2 composition is an indication of the flue gas composition. This variation may be read by means of a galvanometer or potentiometer and is of course easily adapted to recording form.

By taking a determination of CO_2 and then passing a sample through a hot furnace to give complete combustion and making a second determination, the CO content of the original sample can be determined. The electrical method is also used for CO determinations direct by using a somewhat similar wheatstone bridge arrangement. In these CO is burned to CO_2 and the increased temperature in this chamber forming a leg of the wheatstone bridge causes a change in resistance which is indicated by a galvanometer. Naturally if H is present in the gas it burns also and this type of meter really determines the combustible content of the gas.

CO_2 has a specific gravity about 50 per cent above air so that the specific gravity of flue gas varies with its CO_2 content. This is utilized in one type of instrument in which flue gas in one chamber and air in another act on small paddle wheels or vanes. These paddle wheels oppose each other and the excess torque of the gas wheel over that of the air due to its higher specific gravity is a measure of the CO_2 content.

To secure reliable results from gas analysis instruments they must be taken care of. The sampling tubes must be kept open and free from air leaks. The chemicals require renewal at regular intervals. As a

matter of routine, the results obtained with recording instruments should be checked against hand analyses made with an Orsat at intervals which, through experience, have proved sufficiently frequent to insure proper operation.

Once the flue gases pass to the stack, what losses have occurred cannot be recovered. The value in watching the temperature and analysis lies in the possibility of correcting uneconomical conditions as soon after they occur as possible. So intricate, however, is the process of combustion that some undesirable conditions cannot be detected by any one instrument. For this reason a complete record of conditions as indicated by the instruments available in the plant should be kept and scrutinized carefully each day for variations which indicate a lowering of efficiency or the development of dangerous conditions.

Proper firing and boiler operation is not of course shown by any single instrument but by a number of instruments including steam flow meters, the draft gages, CO_2 meter and flue gas thermometer. It is therefore, often convenient to group two or more of these instruments on a single dial or chart. This makes it possible to visualize the variations and many times correct conditions from the relative value of two or more quantities without knowing their absolute values.

Since the weight of air required for complete combustion of a pound of a given fuel is practically a constant, and this combustion generates a definite amount of heat, there is for a definite combination of equipment, fuel and load, a definite relation between the steam output from the boiler and the air required for combustion. An instrument combining these two quantities is, therefore, a definite indication of operating conditions.

Again, since the mean specific heat of flue gas is practically constant for practical operating conditions, and the temperature of the air entering the furnace does not vary greatly, the heat loss in the flue gas for a given fuel is a function of the flue gas weight and temperature. For a given fuel the CO_2 content is an indication of the weight of the gas so that a combination chart showing the CO_2 and the temperature on a single chart is also a measure of the relative efficiency.

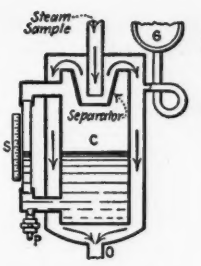


Fig. 2A. Cross section of simple separating calorimeter

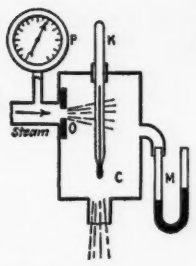


Fig. 2B. Cross section of simple throttling calorimeter

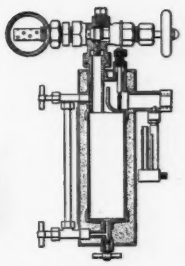


Fig. 2C. Cross section of combination type calorimeter

The boiler also may be considered as an orifice in which the resistance or draft loss across a given section is proportional to the flow so that a combination instrument showing the draft loss and the flue gas temperature also indicates relative operating efficiency. Other readings such as steam flow-CO_2 readings, etc., may be combined on a single chart for the same purpose. All of these combinations must of course be used intelligently by the operating men, kept in good condition and such factors as ash and slag accumulations, leaky settings, broken baffles, incomplete combustion, dirty sampling tubes must be corrected. These combination instruments have merit, however, and are a ready means to increasing economy. Naturally the control panel on which these instruments are mounted is a matter of some importance, a typical installation being shown by Fig. 3. There is sufficient space below the instruments on this panel for combustion control equipment.

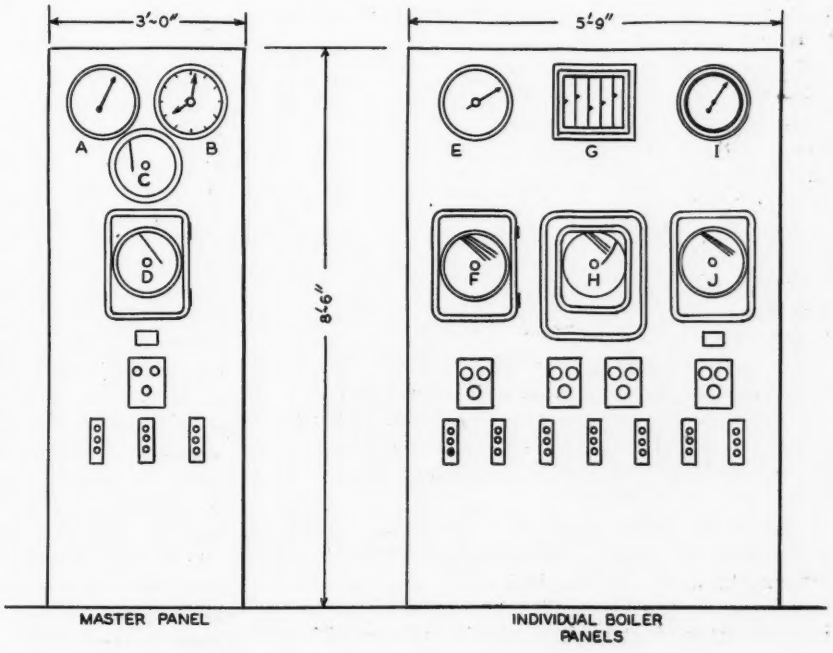


Fig. 3. Layout of an industrial boiler panel. A. Steam header pressure. B. Telechron clock. C. CO_2 recorder. D. Master steam pressure recorder and controller. E. Boiler drum steam pressure. F. Recorder for flue gas temperature entering and leaving the air heater; air temperature entering and leaving the air heater. G. Indicating draft gages for primary and secondary air pressure, furnace, boiler outlet and I. D. fan inlet draft. H. Recorder for steam flow, air flow, superheated steam temperature and steam flow integrator. I. Boiler drum water level indicator. J. Recorder for feed water flow, feed water temperature, drum level and integrator for feed water flow. Control equipment for auxiliaries, pulverizer feeders and fans on board below gages

Carbon losses are not of course indicated by the above instruments, in fact a direct evaluation of smoke loss is impossible. Smoke is, however, obnoxious for many reasons in addition to the fuel loss incurred and most cities have laws to curb this nuisance. Smoke density is usually indicated by the Ringleman Chart, an arbitrary scale of five steps or numbers ranging from solid white to solid black.

Smoke Recorders

Visual methods of detection were employed early, reflecting mirrors or periscope arrangements giving a view of the top of the stack or of a beam of light across the breeching. Development of the photoelectric cell has made possible the development of a recording or indicating meter for this service. Smoke passing the primary element reduces the amount of light reaching the photoelectric cell and thus cuts down the current flow through it. This current variation is an indication of the smoke density.

Somewhat the same principle has been applied to the determination of certain phases of boiler and boiler feed water testing. For instance, a sample of water mixed with chemicals causes a change in turbidity or color. This change in color affects a photoelectric cell and the resulting current flow on a properly calibrated scale can be used as an indication of the hardness of the original sample. The same principle can of course be used for hydrogen ion determinations by the color method.

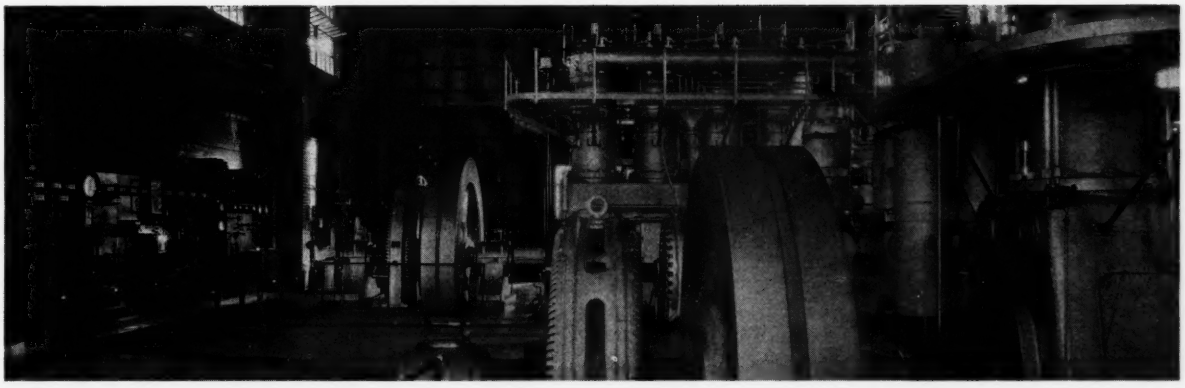
Conductivity methods are also utilized for feed water testing work as well as in connection with condenser leakage testing. Chemicals in water increase its electrical conductivity so that the current flow between two fixed electrodes is an indication of the concentration of certain salts in very much the same way that the hydrometer reading is an indication of their concentration on the specific gravity scale. Electrical determinations are also used successfully in a recording instrument showing the dissolved oxygen in water.

Determinations of the moisture content of steam are not often necessary yet they have to be made occasionally for test purposes. When the moisture is considerable, that is four or five per cent, the separating type calorimeter as shown by Fig. 2A is used. In effect this is a small steam separator and the water present in the steam is simply thrown out into the inner chamber by mechanical means. This chamber is provided with a gage glass and graduated scale to read the amount of moisture collected. The flow of dry steam can be calculated by Napier's rule or may be found by condensing and weighing. Readings are taken over a definite time period. If the orifice is fixed, the dry steam flow is of course a function of the pressure so that the steam pressure, water level on the scale and time of the test are the data needed for calculating the moisture with any given orifice size.

When the moisture is not excessive, the throttling calorimeter as shown in diagrammatic form by Fig. 2B may be used. In this device the steam is allowed to expand through a small orifice open to the atmosphere or at very close atmospheric pressure. The excess heat from the higher pressure steam evaporates the moisture and gives a slight superheat. From the observed temperature of superheat and the pressure (usually atmospheric) it is a simple matter to calculate the moisture in the original sample. Figure 2C shows a universal calorimeter which combines the separating and throttling principles to give a calorimeter adapted to any degree of wetness. The separating chamber is provided with a gage glass, which is not shown by the illustration, for indicating the weight of water which accumulates when the steam is too wet to be superheated. The higher the initial pressure (up to about 400 lb.) the higher the moisture content of the steam that can be handled with the throttling calorimeter. At 80 lb. it is about 3 per cent. at 200 lb. it is about 5 per cent.

In addition to the above power plant instruments there are a number of other laboratory or suggested calorimeters. One is the electric calorimeter in which the electricity required to dry and superheat a sample of steam is measured. The chemical calorimeter which is based on the fact that water absorbs certain chemicals but steam does not; the barrel or condensing calorimeter which is, in simple form, a barrel of water in which steam is condensed and the moisture content calculated from the weight of the water, the temperature rise and the weight of the steam condensed. The throttling or separating calorimeter, or their equivalent the combination calorimeter, is however simple to use, cheap and well adapted to power plant service.

Sheet steel poles for transmission lines are in use in several European countries. These are made of telescoped tapered sections, the longitudinal seams being welded on forms, elliptical in cross section. Length of sections is about 79 in., circumferences running from 12.6 in. outside at the small end and 17.7 in. at the large end for the smallest sections to 59.5 in. at small end and 65.9 in. at large end for the largest sections. Thickness of metal in the smallest sections is 0.03 in. and in the largest, 0.08 in. Twelve sizes of sections are used, from which poles from 7 to 70 ft. tall can be built up. Sections are shipped nested, then drawn into telescope form on the ground by hand tackle and erected as a completed unit. Cross arms are carried on rings which slip over the top section and A-frame poles for angles or anchors are made by braces with rings on the ends. It is claimed that one man can carry and erect a 30-ft. pole and two men can handle the largest ones. Normal working load is 200 to 2500 lb. Poles are set with the long axis of the ellipse across the line. The butt end is dipped in a lead bath to reduce corrosion. Life double that of wood poles is claimed and cost is favorable in comparison as the span between poles can be greater than when wood poles are used. For heavy strains, sections are built of thicker metal. The material used is Patina steel, with copper content 0.2 to 0.3 per cent and tensile strength 38 to 44 t. per sq. in. In case of overload and buckling, only the damaged section need be replaced. Data above is taken from Engineering of London, England.



Photo, Illinois Testing Laboratories, Inc.

Special Instruments *for Improving Performance*

Planimeters, Indicators, Psychrometers, Condenser Leakage Meters and Dynamometers Some of the Many Instruments Needed for Special Services

OF THE INSTRUMENTS used in the engine room, the engine indicator is perhaps the most useful, serving as it does not only as a means of measuring the output of the engine but as an indicator of the setting and condition of the valves. Fundamentally the indicator is a recording pressure instrument with which is incorporated a volume recorder. The resulting chart gives the pressure in the cylinder at any position of the piston and as pressure times volume is equal to power the chart gives a direct measurement of the power developed in the cylinder. The chart drawn is the well known indicator card.

Removable Springs

Indicators are made in many different forms and with carefully calibrated springs to take care of different pressure conditions. The springs are marked or indicated as 40, 60 or 100 lb. springs, indicating that when used with the indicator (usually a ½ in. area piston), the designated pressure will cause a 1 in. movement of the indicator pencil or stylus. Some indicators also have changeable pistons—a 100 lb. spring when used with a ½ in. area piston will be equivalent to a 200 lb. spring if the piston is changed to ¼ area dia.

The springs are made removable. Figure 1 shows the cross section of an outside spring type indicator, so called in contra-distinction to the inside spring type in which the spring is enclosed in a housing above the piston. In the instrument shown the piston C is actuated by the pressure in the cylinder, and this movement is opposed by the spring E. The movement of the piston and hence the movement of the pencil point H is thus proportional to the pressure in the cylinder above or below the atmosphere. The pencil H may be either the lead from a pencil marking on plain paper or a metal stylus marking on sensitized paper. It may be held in contact with the paper or withdrawn from the paper at will by means of a handle J.

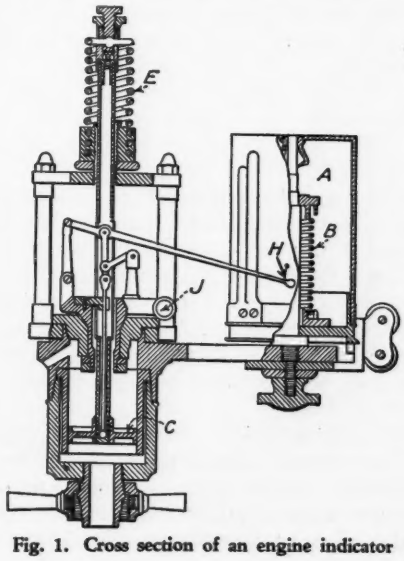


Fig. 1. Cross section of an engine indicator

Special Indicators for High Speeds

Through an accurate leverage system point H moves up and down with a straight line motion parallel with the piston. The usual indicator with a ½ in. area and 2 in. dia. drum is good for speeds of up to about 200 r.p.m. Up to 300 r.p.m. a stiffer spring should be used to reduce the height of the card and the drum preferably reduced to 1½ in. dia. By using a ¼ in. area piston and a smaller drum, speeds approximating 500 r.p.m. can be indicated but as a rule one of the several special high speed indicators should be used for speeds in that range.

The paper upon which the diagram is drawn is wrapped around the drum and held in place by means of the two clips shown. The drum is turned by means of a string passing around the channel at the bottom of the drum and out through the guide at the right to the crosshead. The drum moves in phase with the crosshead being pulled forward by it and being returned by the spring B. This spring opposes the motion of the drum and is coiled up during the forward motion of the crosshead and uncoils itself as soon as the return motion begins.

Reducing Motions

Inasmuch as the maximum card length of a 2 in. dia. drum is between five and six inches, while the engine stroke is sometimes that many feet, some type of reducing motion is necessary. This usually takes the form of a pantograph, pendulum or geared reducing wheel mechanism. The first two are used at the crosshead, the last is ordinarily designed to be attached directly to the indicator underneath the drum. It is of course important that the movement of the drum correspond exactly with the movement of the crosshead so that the reducing motion is a matter of some importance.

One of the important uses of the indicator card is for the diagnosis of engine troubles, valve setting, etc., although it is also of use for determining the power developed by the engine cylinder, the indicated horsepower of which multiplied by the mechanical efficiency of the engine gives the net or brake horsepower of the machine. For calculating the horsepower it is necessary to know the average height of the card. This average height in inches multiplied by scale of the spring used gives the average net pressure in the cylinder, commonly called the mean effective pressure or m.e.p. This is the pressure actually effective in doing work.

The m.e.p. can be estimated by measuring and averaging the height of the card in a number of places but the easiest and most satisfactory method is by means of a planimeter. A planimeter is an instrument which measures areas in square inches. The total area of a card in square inches, divided by its length in inches, gives the average height in inches from which the m.e.p. can be calculated by multiplying by the scale of the spring.

For use with indicator cards, special planimeters have been developed. One of these, shown by Fig. 2, gives the average height or mean ordinate of the card in inches. The point E slides in a slot FG. The indicator card is placed under special clips H and D with the back pressure line on the fixed bottom guide G and one end of the diagram at the edge of guide H. Guide D, which is adjusted by means of slide C, is then moved in until it touches the other end of the card. The card is then traced with the point and the average height of the card read direct from the wheel. Just before tracing the card it is convenient to set the wheel at zero so as to give a direct reading. If this is not done, the wheel must be read before and after tracing and the two readings subtracted to give the desired answer.

Another type of instrument, shown by Fig. 3, has a movable triangular scale corresponding to different springs and gives the m.e.p. direct in pounds per square inch. Before starting to trace the diagram, the planimeter is adjusted by making the distance from the point B to point E equal to the length of the card and by setting the wheel W to zero on the particular scale used.

Other types of planimeters are available either for this particular use or for integrating or determining the area of circular charts. Some of the latter are equipped with special cam arrangements for use with non-uniform scales, for instance the charts used with some flow meters where the flow varies as the square root of the indicated head or pressure difference.

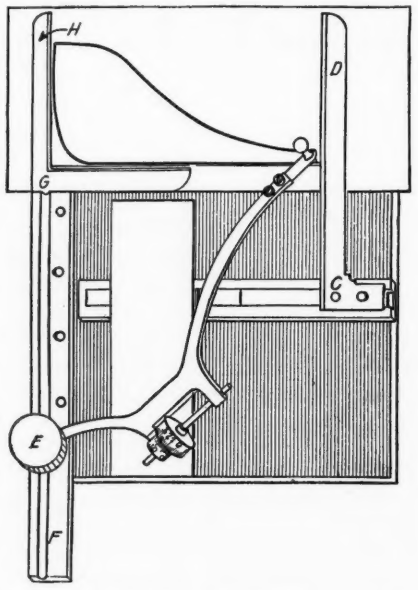


Fig. 2. One type of planimeter that gives the average height of the indicator card in inches

Continuous Indicators

For steam or Diesel engines in power plant service, the usual indicator as described above is satisfactory but for high speed engines, particularly for laboratory and experimental use, special indicators have been developed. Some use optical and some electrical means for recording pressure variations. The usual method of using an indicator is to take a card occasionally and from that and the known speed calculate the power developed. This does not of course take in the variations from stroke to stroke although that can be done

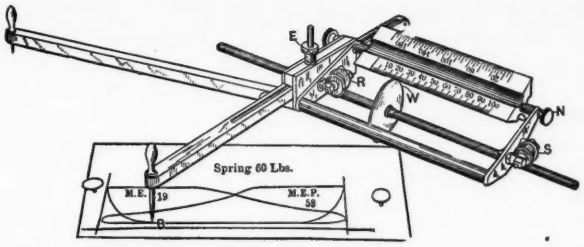


Fig. 3. This planimeter gives a direct reading of the m.e.p. in pounds per square inch

on an indicator with a special drum. On this type, known as a continuous indicator, the cards are taken on a long roll of paper which is moved a short distance automatically at the end of each stroke. Another type automatically averages the m.e.p. of each card and totals the power developed over a period.

Determination of indicated horsepower is simple and can be accomplished quite accurately with steam engines, Diesel engines and compressors. Brake horsepower is usually more difficult to determine, however, unless electrical means can be used. For instance, if an engine drives a generator it is a comparatively simple matter to determine the electrical output of the machine and by making corrections for the efficiency, calculate the output of the engine.

For small temporary testing, however, the prony brake is perhaps the most widely used. Figure 4 shows several simple variations of this type of dynamometer which depends upon the friction between the brake and rotating member. This friction produces a definite upward or downward force at the end of a lever arm and this force is measured in pounds by a scale. The power is then calculated from this force and the known length of the lever arm a.

The two wood blocks as shown by Fig. 4C are simple and quite satisfactory for small amounts of power if carefully fitted. It is too clumsy for wheels much over 15 in. in dia., however, in which case the wood block types of Figs. 2A and 2B are more satisfactory. This type of brake can be used for absorbing as high as 250 hp., although 100 hp. at speeds of below 1000 r.p.m. is usually the convenient upper limit for prony brakes. Rope, plain or with asbestos materials, such as automobile brake lining, is also used, wrapped entirely around the wheel or partially around as in Fig. 4D.

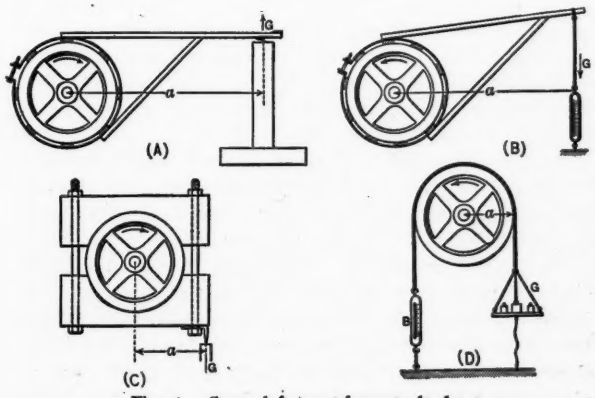


Fig. 4. Several forms of prony brake

Large brakes and dynamometers are unusual today as most engines developing any considerable amount of power drive generators which in themselves serve as very effective power measuring devices. In fact an accurate dynamometer can be made this way either by calibrating the generator or by mounting it in a cradle and measuring the reaction on a scale as with a prony brake.

These dynamometers are largely used for testing automotive engines as they can be used for a variety of speeds and the generator can be used as a motor to determine the friction horsepower of the tested machine. The rotor, with the shaft extended at both ends, is supported on pedestal bearings. The stator is free to move about the axis of rotation, restrained by scales or by a balancing mechanism arranged to register the pull in either direction. The power is absorbed in the generation of electricity. Either the electrical output or the reaction of the stator is an indication of the load.

Hydraulic brakes, some using oil and some water,

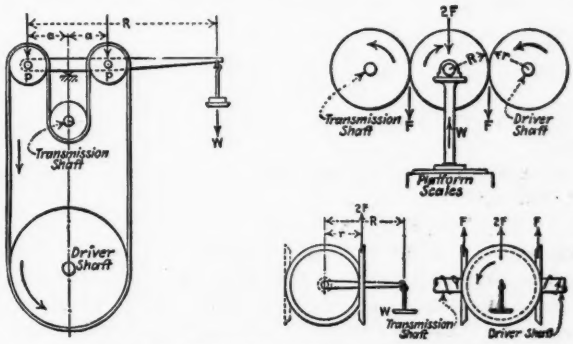


Fig. 5. Three forms of transmission dynamometers

have been developed commercially to a high state and are used widely for testing work. In general they consist of stators and rotors with pockets, cups or vanes, with water or oil forming a transmission medium. The load is regulated either by means of the quantity of fluid or by the proximity or shape of the rotating and stationary elements. Fan brakes are also used occasionally, the power capacity depending upon the size and arrangement of the blades and varying as the cube of the speed. In fact, practically any rotary machine such as a fan or centrifugal pump may be used for this service if properly calibrated.

Transmission Dynamometers

The above are all types of absorption dynamometers, that is the power is absorbed and destroyed by the brake and dissipated in the form of heat. Transmission dynamometers measure the power continuously as it is used and without destroying it. The two types may be compared to measuring steam by condensing it first so that it has no further use as steam, and measuring it by means of a flow meter in which case it is not destroyed but can still be used as steam.

Many of the transmission dynamometers measure the tension in belts by means of lever arm reactions or by means of differentials as shown by Fig. 5. The first is a belt dynamometer and the power is a function

of the weight W and the ratio of both lever arms, but suitable allowances must be made also for friction. The pillow block dynamometer, Fig. 5B, consists of three gear wheels, the middle one being mounted on a pedestal supported on a scale. Some forms omit the middle gear and weigh the reaction of the bearing on the shaft, in this case of course the shaft must be arranged to rest freely on the weighing device. The differential dynamometer, Fig. 5C, is a variation of the above.

Another large group of transmission dynamometers come in the torsion class, a simple arrangement of which is shown by Fig. 5D. The power is measured by the torsion of the springs as indicated by the relative rotation of the two discs. This rotation may be shown in several ways, a stroboscope being one very practical method. In the illustration the discs are arranged to act as commutators insulated from the shafts except for the sections under the brushes shown in black. When in this position an electric circuit is completed causing a click in a telephone receiver. In operation the left hand brush is rotated until a

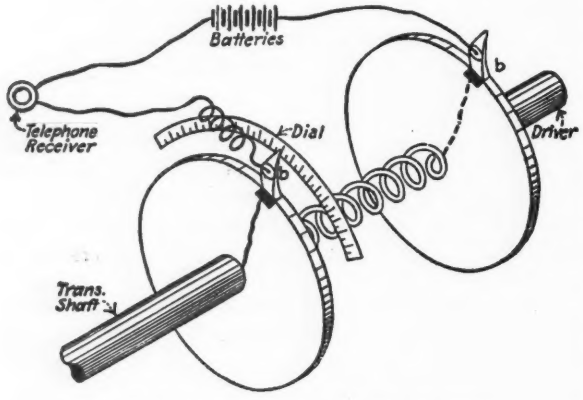


Fig. 6. A simple type of torsion dynamometer

click is heard in the phone, the relative angle of the discs can then be read on the scale and this is of course a measure of the torque.

There are many variations of this type of dynamometer, some of which may be arranged to indicate or even record the torque or power. In some services, for instance marine, such a device is of considerable value and Fig. 7 shows the principle of operation of one such instrument operating directly on a shaft. This is based on the well-known fact that the pitch of the musical tone produced by a vibrating cord depends upon the rate of vibration which in turn is proportional to the square root of the tension. A steel cord is attached tangentially to the shaft and put under tension between two sleeves which are fixed at a known distance apart on the shaft, as shown diagrammatically in Fig. 7.

Twisting of the shaft when transmitting power causes a relative movement of the flanges. This stretches the steel cord, and the tone produced by the cord when set in vibration gradually rises in pitch. This method of measurement is sensitive, and the change of pitch due to elongation of five one-millionths of an inch, corresponding to a torsional deflection of the shaft of approximately the same amount, is plainly indicated.

The torsiometer consists of two units: the torsion element which is fastened on the shaft and revolves with it, and the receiving set which may be located away from the shaft at any conveniently centralized point. The hard alloy steel cord is about 5 in. in length. Located directly above the steel cord is a small electro-magnet, and on making and breaking the current the steel cord is set in vibration. As the cord is vibrating in the magnetic field, it produces an alternating current in the magnet coils, the frequency of this current being the same as the rate of vibration of the cord. As already explained, the rate of vibration of the cord depends on the tension, which in turn is proportional to the torsional deflection of the shaft; so that the pitch of the tone produced by the cord when set in vibration is a direct measure of the amount of torque on the shaft.

Current is led in and out of the torsion element by means of slip-rings and brushes to which are attached the leads for making the connection to the receiving set. In the receiving set is installed a comparison cord which can be stretched at will by a micrometer screw adjustment, the strain thus induced into the cord being conveniently read by means of a magnifying glass on a large scale.

This torsiometer has been used successfully on more than 60 ships for measuring the torque transmitted through shafts from 3 to 25 in. in diameter and transmitting from 75 to 30,000 hp. at engine speeds from 100 to 850 r.p.m. The best results have been obtained with turbine drives because the natural period of vibration of turbine shafts is so much higher than the variation in the torque that there can be no interference. On Diesel engines it has been found that there is a critical speed below which torsional vibrations become too great to permit reliable torsion readings. Compared with ordinary operating speeds, however, this critical speed is usually so low that power measurements in this range are of no importance. At normal operating speeds it is possible to take readings with the same accuracy and ease as in the case of steam turbines.

Relative Humidity

Determination of relative humidity is often necessary. The instrument used by the Weather Bureau is known as the sling psychrometer and consists of two thermometers mounted side by side on a small board equipped with a handle. One thermometer is fitted with a wet wick. When the psychrometer is whirled rapidly in the air this thermometer, known as the wet bulb, is cooled below the normal temperature as registered by the dry bulb thermometer. From these two readings and carefully calculated tables or charts the relative humidity can be determined.

Such instruments are also built as stationary psychrometers or hygrometers, one of the thermometers being equipped with a wet wick as before. Readings are of course affected by air currents and thus may show considerable error unless placed in a positive air current as in a duct or in front of a fan. Many

fibres such as wool, silk and human hair are sensitive to changes in humidity and are used as elements in hydrometers which are made in a variety of forms. Electrical instruments, depending upon the differences in thermal conductivity of dry and humid air have also been adapted for this service.

Condenser Leakage

In condensing power plants, condenser leakage is important for two reasons: first it contaminates the boiler feedwater; second, it causes errors in tests. Whenever a steam-rate test of an engine or turbine is to be conducted by weighing or measuring the condensate discharged by a surface condenser, the amount

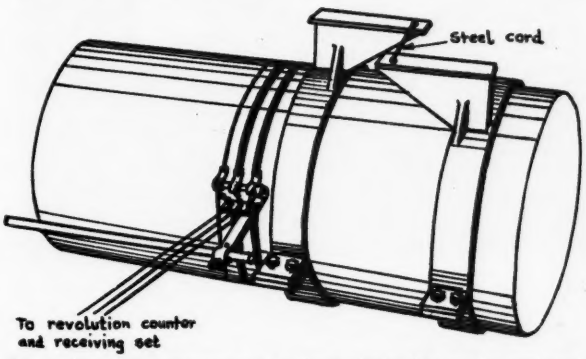


Fig. 7. A torsion dynamometer for large shafts that can be equipped with a remote mechanism

of leakage of circulating water into the steam space of the condenser must be determined and the steam rate of the engine or turbine shall be corrected for the average leakage as shown by leakage tests.

There are five permissible methods for determining condenser leakage listed by the A.S.M.E. Test Codes. Some of the methods can be used with salt circulating water only, and some may be used with either fresh or salt circulating water. Others require accurate apparatus and an experienced personnel, and can be used only when these are available. Some of the methods are carried on when the engine or turbine is running for the regular steam-rate tests.

Qualitative silver nitrate method is only suitable for circulating water containing an appreciable amount of salt, such as sea water or a tidewater mixture of sea and fresh water. It can be used with fresh water provided it is mixed with brine or otherwise chlorinated, as at the suction of the circulating pump. It is the preferred method for such waters when the condenser is thought to be very tight. The test is to be made when the engine or turbine is running. The method depends upon the chemical reaction of silver nitrate with chlorides which are abundant in salt water. Samples of condensate are tested by means of a silver nitrate solution in order to determine if a trace of salt is present. If no trace is found the condenser is known to be perfectly tight. If a trace is found, the quantitative silver nitrate method can be used.

This latter method is suitable for use with salt circulating water and when the engine or turbine is running. Samples of pure condensed steam (which has not passed through the condenser), of condensate from the condenser, and of circulating water are titrated against a silver nitrate solution (using potassium chromate as an indicator) in order to determine the concentration of chlorides in each. Then by calculation the amount of circulating water leaking into the steam space of the condenser is determined. This method requires some readily obtained chemical apparatus and some easily acquired skill.

The short direct-weight method is used with fresh circulating water only. It may be used when circumstances do not permit the use of the electrolytic-conductance method. The method is used only when the engine or turbine is not running and consists in shutting off all steam supply to the unit, running the circulating

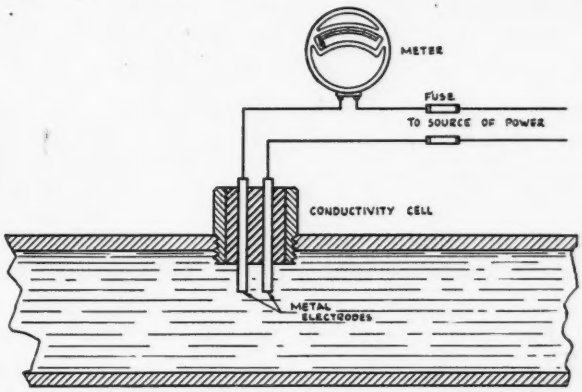


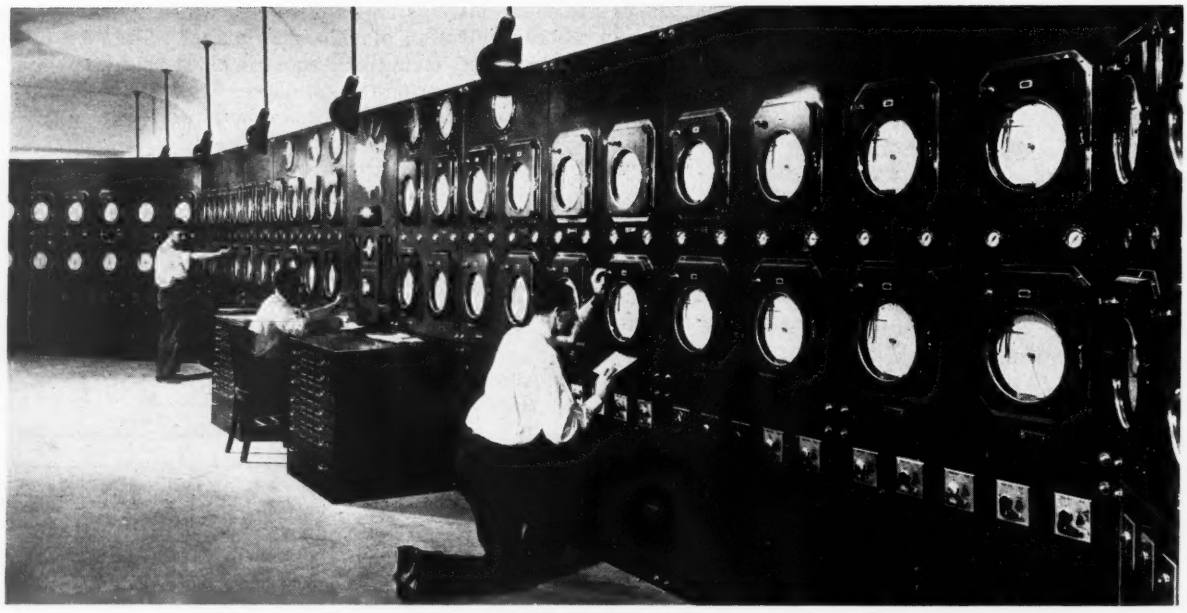
Fig. 8. Simple form of condenser leakage tester

pumps at the same speed as during the steam-rate test, maintaining as nearly as possible the same vacuum in the steam space as during the steam-rate test, and weighing the circulating water that leaks into the steam space as it is removed from the hotwell of the condenser. Such tests are usually made preceding and following the steam-rate test.

The standard direct-weight method is the same as the short direct-weight method, with the addition of some refinements which make for greater precision.

Electrolytic-conductance tests involve a determination of the relative resistance offered to the flow of electric current between electrodes immersed in samples of pure condensed steam from the steam space of the condenser, of condensate from the hotwell of the condenser, and of circulating water. From these data the amount of circulating water leaking into the steam space can be calculated. The test is made when the engine or turbine is running and the greater the amount of solids in solution in the circulating water, the easier it is to apply this method.

A diagrammatic arrangement of the equipment for the electrolytic conductance test is shown by Fig. 8, the method of course being based upon the improved electrical conductance of water as the chemical content is increased. The indications may be by means of a simple ammeter, an ohmmeter or wheatstone bridge. The electrodes to be practical must be made so that they can be inserted easily and removed for cleaning and inspection without difficulty. Such electrodes or conductivity cells are made for permanent use so that they can be installed in the hotwell or hot well line, through a permanently installed gate valve.



Control board on the N. B. C. Radio City Studios. (Courtesy The Taylor Instruments Cos.)

Recording *and* Integrating Mechanisms

Utility of Instruments Increased by Recording and Intergrating Mechanisms. Telemetering Still Further Widens Field

DEVELOPMENT of recording and integrating instruments has been an important factor in bringing the power plant to its present high efficiency. Naturally the central station, with power generation as its major objective, was first to realize the importance of proper instrumentation, and equally important, the necessity for providing men who could appreciate and interpret the data collected. The industrial plant was not, however, far behind in appreciating both the importance of instrumentation and the extensive use that could be made of instruments not only in the power plant itself but in connection with the heat and power services throughout the entire manufacturing plant.

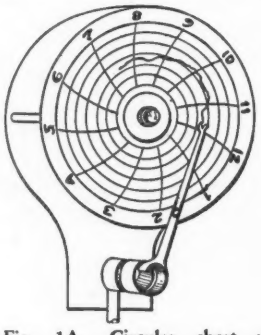


Fig. 1A. Circular chart recorder

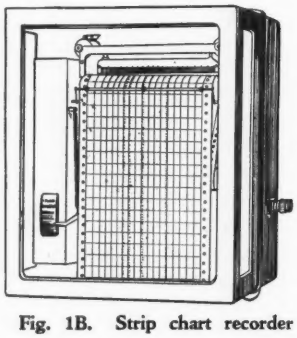


Fig. 1B. Strip chart recorder

Fundamentally the indicating instrument is sufficient for operating purposes, yet the limitations of this type for supervisory purposes is apparent. As the demand increased, the development kept pace with it until today practically anything that can be measured can be fitted with a recording or integrating mechanism. Recording mechanisms are made in many types and designs but the charts have taken two general forms as shown by Fig. 1.

The first, and perhaps the most numerous because of its simplicity, is the circular chart. These are commonly made 6, 8, or 12 in. in diameter and rotated by clockwork or small synchronous motors so that they make one revolution in 24 hr., although this is often made in periods of from a few hours up to a week to meet special conditions. The area of the chart is divided into hour or quarter hour divisions so that events can be definitely located as to time. The scales are sometimes uniform and sometimes non-uniform, the squared and square root scale being common. Pens with ink are commonly used although smoked charts on which a stylus makes a line are also in use.

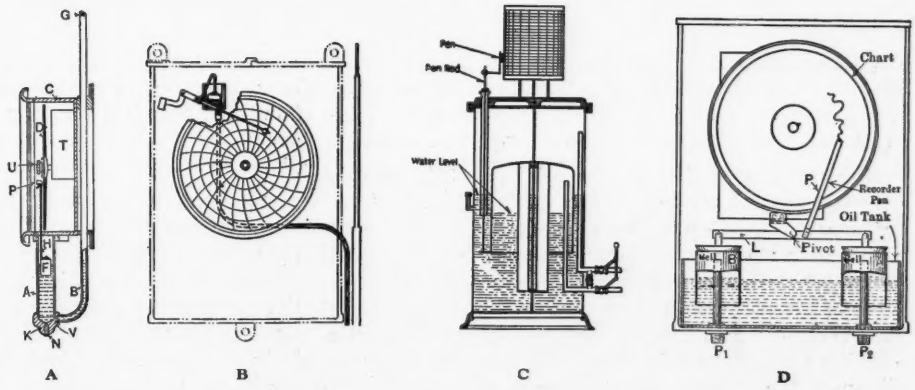


Fig. 2A. Draft gage with pen attached directly to the float. B. Float and pen of simple lever construction. C. A sealed bell driving the pen direct. D. Double sealed bell for differential pressure service

Strip charts as shown by Fig. 1B are used in different widths, usually 6 to 12 in., and in rolls of perhaps a 100 ft. so that they last several weeks, sometimes several months in fact. These instruments are sometimes made with several speeds, that is the speed of the strip may be speeded up from the normal speed of 1 in. per hr. to 1 in. per min. for some particular study. Ink pens are commonly used although in the sensitive electrical instruments, such as millivoltmeters, the indicator is often a simple light wire pointer which swings above an inked ribbon. Periodically a chopper bar drops upon the pointer forcing it sharply against the chart making the record a series of dots. These instruments may be made with as high as six different colored ribbons to give six records on the same chart. For instance, the one recording mechanism may be hooked up to six different thermocouples, the recorder switching automatically from one to the other, each being recorded in its appropriate color on the chart. The instrument shown is a multipoint recorder of this type. Multipoint circular chart recorders are illustrated in a later article and in many of the photographs throughout the issue.

Many indicating instruments can be adopted to recording service by the simple expedient of attaching a pen to what would normally be the pointer. A Bourdon helix, widely used for both pressure and temperature recorders is shown by Fig. 1. Other examples are shown in the previous articles, for instance Fig. 2C of the temperature measuring article and Fig. 3 of the tachometer article and Fig. 8C of the flow meter article. Where motion is involved the construction of a recorder is simple. Pressure changes lend themselves admirably to this purpose and if the quantities can be expressed in terms of pressure the problem is easy.

It is for this reason that many recorders take that form. For instance, Fig. 2 shows four simple adaptions of pressure recording devices. The first is a simple U-tube float with a pen directly attached. The second, a thermometer by the way, has the float attached to the pen by a simple link. The third is again a straight pen attachment on an inverted and sealed bell while the fourth shows a simple and fundamental linkage using two sealed bells.

For low pressures this arrangement is ample but when high pressures are involved, as for instance in flow meters where the pressure may run up to 1500 lb., stuffing boxes through the meter body must be provided to transmit the motion from the float to the pen. Frictionless stuffing boxes for this service have reached a high state of development. Figure 3A shows a flow meter body, float and stuffing box arrangement, while Fig. 3B shows a diaphragm type differential gage for the same service. Sometimes the pen is fitted directly to the shaft running through the stuffing box and swings across the chart on an arc with the stuffing box as a center. In some cases a link mechanism, or cam, is used and in other cases the shaft moves the pen by means of a worm gear.

Of course with flow meters, in connection with which recorders and integrators have perhaps reached their highest development, another factor must be considered. The flow varies as the square root of the head measured by a U-tube manometer so that a pen operated directly by a float as in Fig. 3A would record the head or pressure differential on a uniformly graduated chart. If the chart were to be graduated or marked to read the flow direct a square root scale would have to be used and from 0 to 50 per cent flow would be represented by about one quarter of the total pen travel. Such charts are often used as they give a good open reading over the higher ranges of the chart but they complicate considerably the problem of integration, that is mechanism for totalizing the flow over a period of time.

Many flow meters are therefore designed so that the pen will record the flow direct on a uniform chart. This is done in a number of different ways, the oldest method being to have the float actuate a cam which in turn moved the pen the desired amount. In the case of an orifice meter this cam is a square root curve but in other meters, for instance a V-notch, it may be practically anything. With the most common angle in use the flow varies as the 5/2 power of the head.

The cam is but one method used, however, and a number of others are shown by Fig. 3. Although the flow is proportional to the total head, as measured by the deflection of a mercury or other fluid column, it is customary to measure only the deflection or change of level of one leg. If each leg is of equal area the movement of each leg is half the total. If, however, the high pressure leg is twice the area of the low pressure leg, the deflection of the latter will be twice that of the former although the total deflection between the levels of the two legs will be the same as before. By carefully proportioning one chamber only as in Fig. 3C, the movement of the float can be made pro-

portional to the square root of the total head and the flow can be recorded on a uniform chart. The same effect is obtained by shaping the float itself as in Fig. 3D. Sometimes the bell is used as shown with the low pressure connections inside, sometimes it is inverted and the high pressure connection run inside.

Still another method is shown by Fig. 3E. In this case the manometer swings on knife edges, and its movement is made proportional to the square root of the head by a counterweight swinging on a shaped cam. All the above instruments use a shaft and stuffing box to transmit the float motion from the pressure chamber to the recording mechanism. A magnetic clutch or connection is sometimes used in order to eliminate the stuffing box. These consist essentially of two magnets on opposite sides of a diaphragm, one simple design being shown by Fig. 4D of the flow meter article.

Many of these devices have been further extended for telemetering purposes, that is the transmission of indications of practically any kind over comparatively long distances. Pressures, temperatures, water level, flow, etc., practically any quantity can be transmitted over these systems some of which utilize existing telephone wires for their operation.

Some of them depend upon variation in resistance at the primary instrument, some depend upon the ability of special motor rotors or inductance coil cores to assume the same relative position at both ends of the line or upon the operation of special magnetic clutches. One recent type consists of a mirror mounted on a Kelvin balance. As the mirror is deflected it throws the beam of light on one of two photoelectric cells. The current flow through that side is proportional to the deflection and motivates the remote instrument.

These electrical instruments are described in later articles, many different ones being used as parts of recording or integrating devices. Recording millivoltmeters are in common use with pyrometers, voltmeters, ammeters, wattmeters, conductance meters, etc., with flow meters and CO_2 meters, etc. One of the most accurate and widely used recording instruments, adapted of recent years to a multitude of services, is the null type potentiometer. Deflection of the galvanometer needle or balance coils simply acts as a pilot to actuate a motor driven slide or potentiometer contact until balance is obtained.

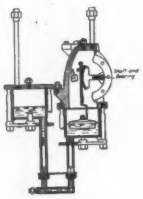


Fig. 3A. Manometer of the float type

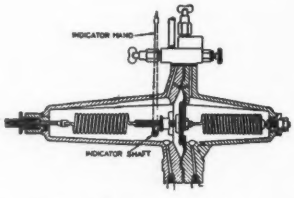


Fig. 3B. Differential diaphragm gage

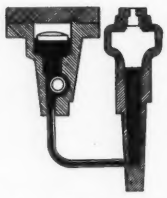


Fig. 3C. Shaped chamber manometer

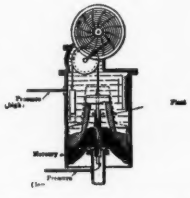


Fig. 3D. Sealed bell of variable section

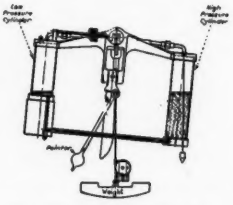


Fig. 3E. Tilting U-tube on knife edge

Integrating devices for mechanical type flow meters are of two general types. In the first, a gear or disc with a clutch or ratchet arrangement is turned periodically, the stroke of the turning element being limited by a cam or other arrangement moved proportional to the flow. In the second the integrating device is moved radially on a revolving disc. At no flow the counter wheel is at the center, at maximum flow it is at the periphery of the disc. With a uniform flow chart the travel of the counter wheel is proportional to the flow and the total travel as indicated on the counter is a measure of the total flow.

Of course the above applies only to the mechanical type of meters. Of recent years the electric type instruments have been highly developed. Electric instruments have one decided advantage, the recording and indicating instruments may be duplicated and they may be located regardless of the location of the flow meter body or other primary device. With electric flow meters, for instance, the quantities actually measured may be electrical quantities, resistances, conductance, voltage, amperage, etc., or the change in electrical properties by the primary device may be used to actuate the indicator recorder or integrator by a combination of electrical and mechanical means.

These electrical type flow meters can be constructed without stuffing boxes. In one instrument the rising mercury column short circuits graduated resistance elements. In another, the rising mercury column acts as the core of a coil; in others, the float carries an iron core which passes through inductance coils; the electrical properties of the circuit being changed in each case with the level of the mercury and these changes are used as a measure of the flow.

Recording instruments can be of great assistance to the operating department both as an aid to supervision and as a guide to better operation. It must be remembered that careful calibration is an important part of their supervision, however, and that they cannot be expected to run indefinitely without attention. The charts must be changed regularly, at the same time each day, and carefully registered so that abnormal operation can be definitely located in respect to time from the record. After the charts have been removed and studied they should be carefully filed according to date so that they are easily accessible for inspection later on. They are particularly useful in cases of accidents, arguments, for improving conditions of operation, coördinating various departmental activities and for planning extensions. If conditions were such that the purchase of a relatively expensive piece of equipment like a recorder was justified, they warrant sufficient care and supervision to make the records useful. If conditions change so that it is no longer serving a useful purpose, it should be changed to a location where it can be usefully employed.

ELECTRICAL INSTRUMENTS

Basis of Electrical Measurements—Principles Involved. Classification of Measurements. Accuracy of Various Types of Instruments

AS POINTED OUT in the introductory articles, the measurement of any given quantity consists, fundamentally, in its comparison with another quantity of the same kind and of known magnitude, chosen as a unit. In electrical measurements the comparison is usually indirect, two or more measurements being required in passing from the quantity to be measured to the unit quantity. Electricity reveals its presence by the effects that it produces and electrical measurement consists essentially in comparing these effects with similar effects of a standard quantity of electricity.

To cause an electric current to flow through a circuit it is necessary to impress a potential difference between the terminals. This potential difference is usually expressed in volts and the resulting current, expressed in amperes, always produces two effects. First, an external magnetic field encircling the conductor and proportional to the current and second an internal heating of the conductor due to agitation of its molecules which is proportional to the square of the current. If the conductor is a liquid compound or electrolyte, the passage of current also produces a separation of its constituents, causing a liberation of gas or deposition of metal, the amount of which is proportional to the current and to the time it passes.

All these effects of current are used as bases for measurement together with others based purely upon a potential difference between two conductors. When there is a difference of potential between two conductors an electrostatic field exists between them. This field can be measured in terms of its attractive or repulsive influence. Again in vacuum tubes electrified particles can be made to travel across the space between oppositely charged electrodes. These particles can be deflected by electrostatic or magnetic fields which also may be used as a basis of measurement.

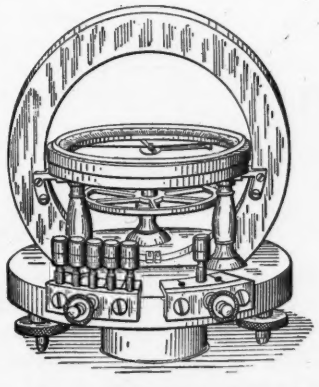


Fig. 1. Tangent galvanometer

Nearly all of these effects are reversible; for example, the introduction of a magnetic field in an electric circuit "induces" an electromotive force in the circuit which causes a current to flow; also, the heating or cooling of a junction of two conductors creates an electromotive force. Electrical instruments using these principles are in common use.

In any metallic conductor, the steady current in amperes is equal to the potential difference in volts between its terminals divided by its resistance in ohms. This is Ohm's Law, which may be expressed in three ways as follows: $E = RI$; $I = E \div R$; and $R = E \div I$. In each of these three cases E is the electromotive force or potential difference in volts between the terminals of the circuit; R, the resistance of the circuit in ohms; and I, the current in amperes. This law, despite its simple nature, is of enormous importance and forms the basis of nearly all resistance measuring devices. These form a very important section of electrical instruments and, of course, the principles involved in these resistance measuring instruments in many instances are also involved in current and voltage measuring instruments.

Since the power in an electric circuit is the product of the current, in amperes and the potential in volts, it is possible to build an instrument with two elements, a voltage element and a current element, which effects this multiplication electrically. This instrument is the indicating wattmeter. Energy, however, involves a time element and watthour meters integrate the total amount of power consumed over the number of hours involved. It is, however, possible to measure power and energy simply by means of ammeters and voltmeters and effecting the multiplication mathematically.

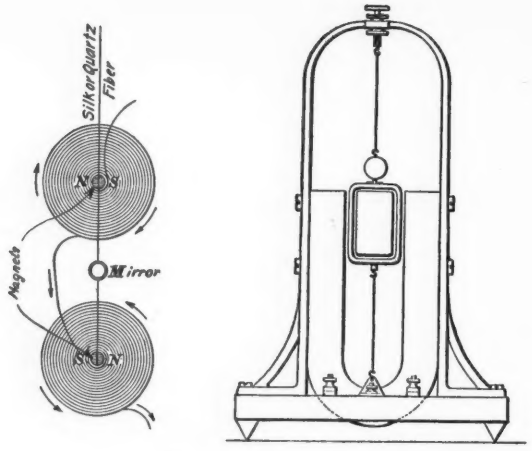


Fig. 2. Kelvin galvanometer
Fig. 3. The D'Arsonval principle

Inductance and capacity are two properties of electrical circuits which are of great importance in alternating current circuits, particularly these involving high frequencies and their measurement is accomplished largely by the use of "bridge" circuits similar to those used in the measurement of resistance. Inductance is intimately related to the magnetic field which surrounds current carrying conductors and has the effect of inducing an opposing electromotive force whenever the current in the circuit diminishes or increases. Its effect, therefore, is analagous to that of inertia in mechanics which causes a mass to resist change of its velocity. The unit of inductance is the Henry[1]. A circuit has an inductance of one Henry when a rate of change of current of one ampere per second induces in the circuit an electromotive force of one volt.

The effect of capacity is exactly opposed to that of inductance and corresponds to the property of elasticity in mechanics. The unit of capacity is the Farad.

The foregoing are the principle quantities with which we are concerned in electrical measurements. There are others, of course, such as power factor and frequency, but these are derived units involving time elements. Power factor, for example, consists merely in the measurement of the relative displacement in time of two electrical forces. Frequency also has to do with the rate at which electrical forces vary in the circuit. The instruments used in the measurement of these quantities involve the same basic principles that are used in the simple measurement of the forces without respect to time.

For convenience in comparing these various quantities and the bases of their measurement, we may list them as shown in Table I.

Precision of Instruments

In general there are three classes of measurements relative to the degree of precision obtainable. 1. High precision measurements; those made at the various national standardizing laboratories in connection with the establishment and maintenance of standards. In this work every precaution is observed to maintain the highest possible accuracy. Secondary standards are standardized with a precision of one part in 100,000. 2. Commercial laboratory measurements in which the object is to secure results which are reliable and accurate but only to the extent justified by commercial and engineering requirements. In this class the demands of accuracy are of the order of one or two parts in 2000. 3. Commercial measurements. Those involved in the production, distribution and sale of energy or other electric commodity or utility. In such measurements the cost of so high a degree of accuracy as is striven for in class 1 or even 2 is not justified. A precision of the order of 1 part in 1000 or as high as 10 parts in a thousand is satisfactory. The present tendency, however, is to narrow the limits as the art develops and greater refinements are introduced.

[1]After the American physicist, Joseph Henry.

Table I. Electrical Quantities Measured by Instruments

Quantity to be Measured	Practical Unit	Definition of unit
Current	Ampere	Deposition of 0.00111800 grams of silver per second
Resistance	Ohm	106,300 centimeters of mercury 1 sq. mm. section (14.4521 grams) at 0 deg. C.
Electromotive force	Volt	Applied to a resistance of 1 ohm produces a current of 1 ampere
Power	Watt	1 Volt-ampere
Quantity	Coulomb	1 Ampere-second
Energy	Watt-hour	Energy expended in 1 hour when rate of expenditure is 1 watt
Inductance	Henry	1 volt for increase of current at 1 ampere per second
Capacity	Farad	1 Coulomb for 1 volt

Table II. Common Types of Electrical Instruments

Measuring Instruments	
Indicating	Laboratory
Ammeters	Galvanometers and Voltmeters
Ohmmeters	Resistance standards Wheatstone bridges
Voltmeters	Standard Cells, Potentiometers, Electrometers
Wattmeters	
Quantity meters	Voltammeters Ballistic galvanometers
Watthour meters	Watthour meters Inductance bridges Standard inductances Variometers Capacity bridges Standard condensers

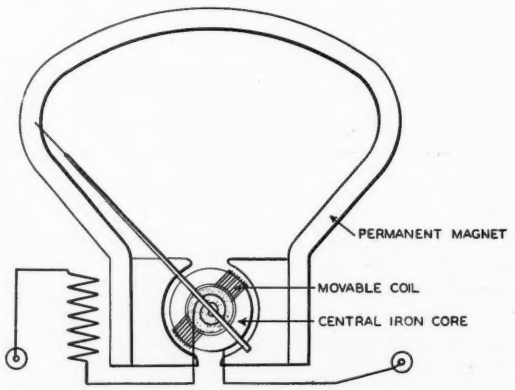


Fig. 4. The elements of the D'Arsonval type galvanometers, moving coil permanent magnet type of instrument

The question of accuracy is of the utmost importance in the art of measurement and regardless of what class of measurements are involved, high precision, commercial laboratory or commercial, every effort must be made to reduce the errors to the minimum possible. In any kind of measurement there are two

classes of errors, a, systematic; b, accidental. The first class affects each result in a series of similar observations in the same manner, as for example, an error in the standard used. The second class includes those over which the observer has no control, such as observational errors in reading an indicating instrument.

Accidental errors, unlike systematic errors, are as likely to be negative as positive and therefore tend to eliminate themselves from the mean value as the number of readings is increased. For this reason the mean value of a number of readings, as a rule, will give a greater degree of accuracy than a single reading. The precision of the result, however, does not increase directly as the number of readings but only as the square root of the number of observations made. This is in accordance with the theory of probability.

Current and E.M.F. Measuring Instruments

Current measuring instruments are conveniently divided into two classes: a, Galvanometers or sensitive laboratory instruments for measuring very small currents, and b, ammeters or indication pointer instruments for large currents. Strictly speaking the term galvanometer applies to many other instruments for measuring currents, such as voltmeters, ammeters, oscillographs and even frequency meters but in general the term applies only to those instruments used for measuring small currents and using the electromagnetic principle exclusively.

Galvanometers again are divided into two types, the moving needle and the moving coil types respectively. The first involves the original discovery of Oersted in 1820—that if a conductor is stretched directly over a pivoted magnetic needle and parallel to it, the needle turns at right angles to the conductor where a current passes through it. Practically, however, instead of using a single conductor, increased sensitivity is obtained by suspending a small permanent magnet at the center of a coil of wire through which the current flows.

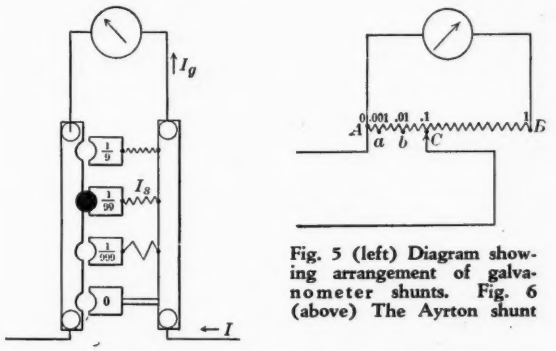


Fig. 5 (left) Diagram showing arrangement of galvanometer shunts. Fig. 6 (above) The Ayrton shunt

In the moving coil type, a very light coil of five wires is suspended in a permanent or electromagnetic field. The current being measured flows through the coil and the interaction of the field due to this current and that of the steady field causes deflection. This is the principle used in the D'Arsonval, vibration and electrodynamometer type instruments. Moving magnet type galvanometers are represented by the tangent and the Kelvin galvanometers.

The tangent galvanometer is obsolete but since it is of historical importance and illustrates the principle of the moving needle type simply and clearly, it is shown here. It consists simply of a magnetic needle pivoted (or suspended) at the center of a vertical coil

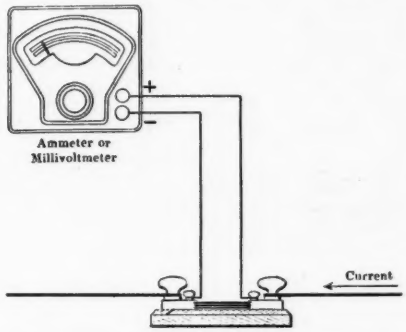


Fig. 7. Ammeter with an external shunt

through which the current to be measured is passed. Since the earth's magnetic field is the controlling force, the plane of the coil is made parallel to the earth's field.

Among the most sensitive of galvanometers is the Kelvin or astatic type. This is of the moving needle type and consists of two magnetic needles fixed parallel to each other on opposite ends of a light quartz rod and oppositely directed, each being at the center of a pair of coils through which the current to be measured is passed. Since the windings of each pair of coils are in opposition, the moving system is almost, but not quite, astatic (free from the influence of external fields).

The exterior field, which is the earth's field is controlled in direction and strength by one or more controlling magnets placed on top of the instrument. In this way the exterior field can be reduced to any extent. A small mirror is attached to the needle system and the deflections are read by a telescope and scale or by a lamp and scale. A common sensitiveness of a galvanometer of this type is a deflection of 1 millimeter of a beam of light on a scale at a distance of 1 meter, for 10^{-9} amperes, but some galvanometers of

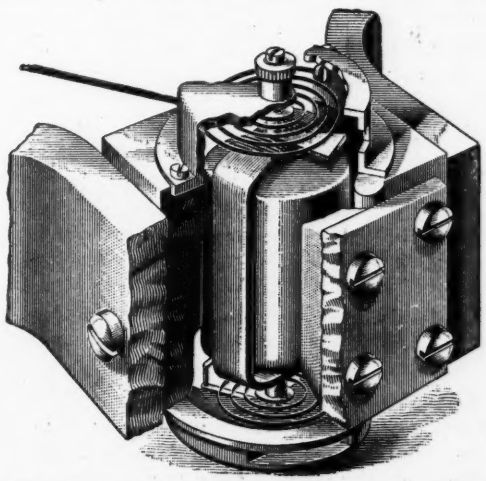


Fig. 8. Details of the D'Arsonval movement as used in modern voltmeters and ammeters

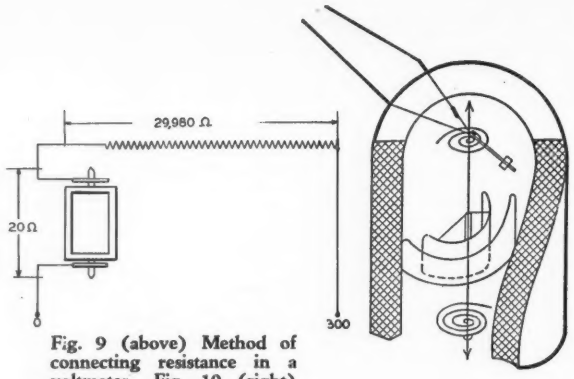


Fig. 9 (above) Method of connecting resistance in a voltmeter. Fig. 10 (right) Iron vane type of instrument

this type are made with a sensitiveness of even 10^{-12} amperes.

A modern version of the Kelvin galvanometer is the Broca galvanometer in which the magnets are two steel wires suspended vertically, close together and with consequent poles at the center.

The D'Arsonval Galvanometer

While the galvanometers which have been described are interesting from a purely scientific point of view, they are not suitable for every day commercial use. For this purpose a more rugged mechanism is necessary. The galvanometer which is most generally used today is the D'Arsonval type, the principle of which is shown in Fig. 3. It consists of a coil of very fine wire suspended between the poles of a permanent magnet. As shown, this instrument does not possess the degree of ruggedness required in commercial service and more practical forms have been developed.

The form universally used is shown in Fig. 4. This type of mechanism is used not only in galvanometers but also in voltmeters and ammeters and many other electrical instruments. In this case the movable coil at the center of the magnet poles is suspended between jeweled bearings. The current is conducted to the coil by a helix of fine wire mounted similar to a hair spring on the balance wheel of a watch. To increase the strength of the magnetic field in the region occupied by the coil, a cylindrical iron core is usually mounted in the central space enclosed by the coil. Further details of this mechanism will be described in connection with ammeters, but enough is given here to describe the principle.

Galvanometers of this type are usually provided with zero center scale, so as to give either positive or negative deflections. Special provision is included for adjusting the pointer to the zero center. They are practically independent of the earth's field or other external field and the period of oscillation can be made short. It is perhaps the most rugged instrument of its kind available and can be used for a wide variety of purposes. Ordinary commercial forms will give a deflection of 1 scale division for as low as a quarter of a microampere.

It is not our purpose here to describe in detail all the various forms of galvanometers that have been developed because most of them are laboratory instruments requiring great care in handling and used only for laboratory purposes, but we will mention briefly the most important types.

There is, for example, the Erinthoven string galvanometer which consists simply of a single strand of very fine wire (often silvered quartz) suspended between the poles of a powerful electromagnet. This is a very sensitive instrument and responds to extremely rapid changes of voltage but it is a delicate instrument which must be read by a microscope and therefore is of little importance in ordinary electrical work. Ballistic galvanometers are used to measure quantity of electricity such as the discharge of a condenser. Differential galvanometers are provided with two sets of coils by means of which two currents may be compared simultaneously.

The vibration galvanometer is the only galvanometer which is peculiarly an alternating current type galvanometer. True, other types may be used either on direct or alternating current but the vibration type can be used only with alternating current. The latter is made in either of two types, a moving coil type and a soft iron magnet type but in both types the moving elements vibrate at the frequency of the current being measured with an amplitude which is proportional to the strength of the current.

An important class of galvanometers are those utilizing the dynamometer principle. Here use is made of the electrodynamic action between a movable coil suspended between two or more fixed coils, all the coils being energized. These instruments are used extensively in the measurement of alternating currents

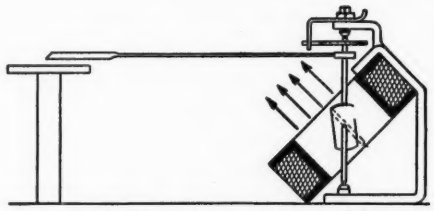


Fig. 11. Inclined coil, iron vane type of instrument

because they can be calibrated with direct current for a wide range of measurements of current and power. The a.c. moving coil galvanometer with electromagnetic field uses a moving coil of the D'Arsonval type but the permanent magnet is replaced by a laminated soft iron magnet excited with alternating current.

Thermo-galvanometers utilize the heating effect of the current passing through a fine wire. The temperature rise is measured by a D'Arsonval galvanometer connected to a thermo-electric junction placed close to or touching the heater wire. In another type of galvanometer, the hot wire galvanometer, the expansion of the wire due to the heating effect of the current is the measuring force.

Electrostatic galvanometers operate upon the principle that two bodies at different potentials attract each other. In the practical instrument one or more thin metal vanes are suspended by a fine wire between two or more stationary vanes, so shaped that when excited the movable vanes swing toward the fixed vanes between which they are interleaned. Such instruments require no appreciable current and will operate on potentials of about 1 v. upward.

While the oscillograph is not ordinarily thought of as a galvanometer, actually it is. Oscillographs essentially are galvanometers capable of following rapid fluctuations in the current. The Einthoven and the vibration galvanometers both are suitable for use as oscillographs but other types have also been developed. Their principal requirement is that the inertia of the moving systems be as low as possible, the natural period of oscillation high and the damping as nearly as possible critical.

Ammeters and Voltmeters

Ammeters and voltmeters, as their names imply, are instruments used for measuring currents in amperes and potentials in volts directly. They operate on the same basic principles as do galvanometers and they are considered together here because in many instances they are similar in construction. These instruments for the majority of purposes are of the electromagnetic type but thermal or hot wire instruments are used for alternating current especially for those of high frequency such as those used in radio work.

Electromagnetic instruments are of various types; in addition to the moving magnet and moving coil types used in galvanometers there are moving soft iron dynamometers and induction instruments, all of which can be used with alternating currents, the last being for alternating currents only. All of these instruments also may be made in either the indicating or recording types.

Moving Magnet Type

Moving magnet type ammeters and voltmeters do not find much application today but they are of historical importance because the first direct reading voltmeters and ammeters used were of this type. Their principle of operation is similar to that of the tangent galvanometer except that the controlling field is a powerful permanent magnet instead of the earth's field. In the original instruments, a small coil encircled the needle and the whole system was fixed between the poles of a permanent magnet.

Although this instrument is essentially an ammeter it can be used as a voltmeter by winding the coil with fine copper wire and connecting a high resistance in series with it so as to make the resistance of the whole instrument practically constant. The current will then be proportional to the voltage across it. This arrangement of course is not confined to this particular form of instrument—it can be used with almost any type of ammeter.

The moving coil type of ammeters and voltmeters in use today are almost universally of the D'Arsonval type, similar in every way to the D'Arsonval gal-

Table III. Classification of Ammeters, Voltmeters and Wattmeters

TYPE	CIRCUIT	VOLTMETER	AMMETER	WATTMETER	LOAD
MOVING MAGNETIC NEEDLE	D.C. NOT USED MUCH AT PRESENT	MAGNETIC NEEDLE	PERMANENT MAGNET, SHUNT	NOT POSSIBLE	LOAD
MOVING COIL-PERMANENT MAGNET	D.C. USED ON A.C. WITH COPPER OXIDE RECTIFIER	MOVING COIL		NOT POSSIBLE	LOAD
ELECTRO DYNAMOMETER	D.C. OR A.C. A.C. STANDARD				LOAD
SOFT IRON VANE	D.C. OR A.C. USUALLY A.C.	SOFT IRON VANES		NOT PRACTICABLE	LOAD
THERMAL	D.C.-A.C. HIGH FREQUENCY	THERMOCOUPLE, HOT WIRE	THERMOCOUPLE, HOT WIRE	WATTMETER NOT GENERALLY USED	LOAD
ELECTRO-STATIC	A.C. OR D.C. HIGH VOLTAGE			WATTMETER NOT GENERALLY USED	LOAD
INDUCTION	A.C. ONLY		TRANSFORMER		LOAD

vanometer already described but having a scale graduated in volts or amperes or in millivolts or milliamperes. Indeed, all of these instruments whether voltmeters or ammeters are simple millivoltmeters. In the case of ammeters, the terminals of the moving coil are connected across a resistor (shunt) which is in turn connected in series with the main circuit in which the current is to be measured.

With this arrangement the instrument actually measures the voltage drop across the shunt. Since this voltage drop (by Ohm's law) is proportional to the current flowing through it, it is obvious that the instrument can be calibrated to indicate directly in amperes. A millivoltmeter, therefore, may be made an ammeter of any range by simply changing the resistance of the shunt.

This principle also applies of course in the use of galvanometers where currents greater than the rated currents of the galvanometer have to be measured. There are two common types of shunts. One type, Fig. 5, consists of three or four separate resistances which are plugged in parallel with the galvanometer, one at a time. These are so adjusted in value that, with a given current to be measured, the successive galvanometer currents are in the ratio of 10 to 1. Referring to Fig. 5 when the plug is entirely removed, no shunt is connected across the galvanometer and the entire line current, I, flows through the galvanometer. When the plug is in the uppermost (1/9) position, 1/10 of the line current goes through the galvanometer and 9/10 goes through the shunt.

The other type of shunt used is the Ayrton shunt shown in Fig. 6. In this case a permanent resistance A B is connected across the galvanometer terminals. One line terminal is permanently connected to one end of this resistance and the other line terminal, C, is movable and can be connected to various points along A B. With a fixed line current the maximum galvanometer current is obtained when C is at B. If point C is moved to a, where the resistance Aa is one one-thousandth of the total resistance AB, the galvanometer current will be one-thousandth of its maximum value. The advantages of the Ayrton shunt are that it is applicable to any galvanometer regardless of the galvanometer resistance, and that it gives a constant value of damping in open-circuit ballistic measurements due to the constant resistance of the shunt across its terminals.

The same principles of measurement hold in the case of ammeters but with ammeters the shunts usually are of a different form. A typical case of the application of the shunt in connection with an ammeter is shown in Fig. 7. Here the voltage drop across the shunt is $V_s = I_s R_s$ where I_s and R_s are the shunt current and shunt resistance respectively. The resistance of the shunt is usually extremely low compared to that of the instrument. For full scale deflection the drop across a shunt usually is of the order of 50 millivolts. The current taken by the instrument itself is usually about 0.01 amp.

The D'Arsonval type of ammeter has already been generally described under the subject of galvanometers. The essential parts of the instrument are shown in Fig. 8. The complete internal arrangement when used as a millivoltmeter is shown in Fig. 4. The moving coil consists of very fine silk covered copper wire wound on an aluminum bobbin. This aluminum bobbin, besides supporting the coil mechanically, makes the instrument highly damped.

This damping is due to the currents set up in the aluminum because of its cutting and magnetic field. The moving system is supported at the top and bottom by hardened steel pivots turning in cup shaped jewels, usually sapphire. This method of supporting makes the instrument portable, whereas the D'Arsonval galvanometer, as originally designed and as illustrated in Fig. 3, is not readily portable. The current is led in and out of the coil by two flat spiral springs, one at the top and the other at the bottom of the coil.

These springs also serve as the controlling device for the coil—any tendency of the coil to turn is opposed by these two springs. The top and bottom springs are coiled in opposite directions so that the effect of change of temperature, which causes a spiral spring to coil or uncoil, will not cause the needle to

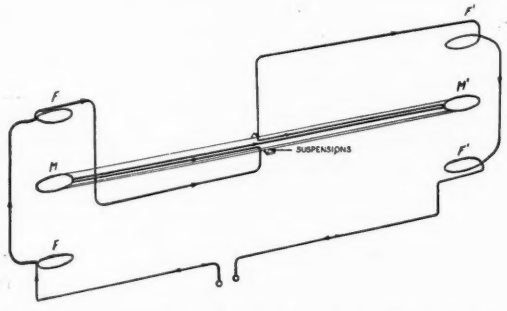


Fig. 12. Diagram showing principle of the Kelvin balance

change its zero position. This moves over a scale which may be graduated in volts or amperes. Because of the radial field, the deflection of this type of instrument is practically proportional to the current in the moving coil so that the scale of the instrument has uniform graduation.

Use of Rectifiers for Adapting D'Arsonval Instruments for A.C. Measurement

This is the type of instrument most used for direct current work. It is essentially a direct current device but recently it has been adapted for use on alternating current by means of the copper-oxide rectifier. These rectifiers have proved very useful in the measurement of alternating current when low energy consumption is necessary. A copper oxide full-wave rectifier is mounted inside the instrument case and connected to feed full wave rectified current to the moving coil. The D'Arsonval instrument deflects proportional to the average value of the rectified wave. The dial is calibrated to read in terms of effective or root-mean-square values. A sensitivity of from 1000 to 10,000 ohms per volt can be obtained.

When D'Arsonval instruments are used as voltmeters, the moving coils are usually wound with more turns and of finer wire than in the case of an ammeter. In addition a high resistance (multiplier) is usually connected in series with the coil as shown in Fig. 9.

By Ohm's law the current through the instrument is proportional to the voltage, so that the instrument scale can be graduated in volts. The resistance required is easily determined. Assume that an instrument gives full-scale deflection with 0.01 amp. in the moving coil and that the coil resistance is 20 ohms. If it is desired that the instrument indicate 300 v., full scale, the total resistance of the instrument circuit must be

$$R = E \div I = 300 \div 0.01 = 30{,}000 \text{ ohms}$$

As the instrument has a resistance of 20 ohms, this means that 29,980 ohms additional are necessary.

The range of a voltmeter having its resistance incorporated in the instrument may be increased by the use of external resistance connected in series with the instrument.

Moving Soft Iron Type Ammeters and Voltmeters

Moving soft iron instruments are simple and inexpensive and can be used both for direct and alternating current measurements. Their principle of operation is simple. If a current is passed through a coil, a piece of soft iron will be drawn into it and if a suitably shaped piece of soft iron is pivoted and provided with a pointer a very useful form of ammeter can be made. If the coil is wound with fine wire and a series resistance added, the instrument becomes a voltmeter.

There are a number of different types of soft iron instruments. The first instruments of this type were introduced by Ayrton and Perry in 1884 and others by Lord Kelvin, Schukert, Siemens, Nalder and Weston. The last two are based on what is known as the repulsion principle, having two soft iron rods lying parallel to one another and to the axis of the coil. When the coil is energized, the two rods are magnetized with the same polarities and consequently repel one another. Therefore, if one is fixed and the other is pivoted and provided with a pointer, deflections will be produced.

An example of this type of instrument is shown in Fig. 10. A small strip of soft iron bent into cylindrical form is mounted axially on a spindle which is free to turn. Another similar strip which is more or less wedge shaped and with a much larger radius is fixed inside the coil. When the current flows through the coil both iron vanes become magnetized. The upper edges of the strips always have the same polarity and the lower edges also are always of the same polarity but when the upper edges are north poles the lower edges are south poles. Therefore, there will always be repulsion between the upper edges and between the lower edges, causing the coil to move against the action of a spring.

Another method of using the iron vane principle is shown in Fig. 11. This is the Thomson Inclined coil type of meter. A small iron vane mounted obliquely on the spindle. When the pointer is at zero, this vane lies at an angle to the coil axis. When current flows in the coil, the vane attempts to take such a position that the direction of its axis shall coincide with that of the magnetic field which acts along the coil axis. In seeking this position the vane turns the spindle which carries the pointer.

Dynamometer Type Instruments

Dynamometer Instruments form an important class of current measuring instruments as they are equally suitable for direct or alternating circuits. They depend fundamentally upon Ampere's discovery (1820) that parallel conductors carrying current attract each other if the currents are in the same direction or repel each other if they are in opposite directions. The prototype of the modern dynamometer instrument was the Siemens electrodynamometer. This instrument, now obsolete, consisted of two stationary coils in series with a moving coil suspended between them by a silk fiber. The terminals of the moving coil were brought to the axis of rotation and connection was made through mercury cups.

The deflecting force was opposed by a spiral spring which was twisted by hand in the so-called torsion head until the moving coil was brought back to the zero position so that the relative position of the fixed and movable coils was always the same. The angle through which the torsion head had to be twisted was proportional to the square of the current in the coils, hence also to the heating effect of the current. The instrument is calibrated with a known direct current. An alternating current giving this same deflection has the same heating effect as the direct current. Hence the effective alternating current amperes squared are equal to the direct current amperes squared for equal settings of the torsion head.

Another form of dynamometer is the Kelvin balance shown in Fig. 12. In this, two coils, MM′ are attached to opposite ends of a beam which is supported at the middle and free to move. Each coil moves between a pair of fixed coils, FF and F′F′ and all the coils are connected in series in such a manner that the movements of all the forces on the movable system, taken about the beam axis are cumulative, thus tending to produce rotation. In the Kelvin balance the controlling force is a weight moved along a graduated scale attached to the beam supporting the movable coils. Neither the Siemens dynamometer nor the Kelvin balance are portable nor direct reading and their use has been practically superseded by more convenient instruments of the dynamometer type.

The general construction of a portable direct reading type of electrodynamometer is shown in Fig. 13. Two fixed coils are so connected that their magnetic fields act in conjunction. These coils may be considered as being two parts of a single coil, opened in the middle to permit the spindle of the moving coil to pass through. The movable coil is mounted on a vertical spindle, the turning of which is opposed by two spiral springs which also carry current into the coil. The action is essentially the same as in the previously described dynamometers except that the springs provide the controlling force. Indeed, the indicating type of dynamometer instrument is equivalent to the permanent magnet moving coil type of instrument except that the magnet is replaced by the fixed coil. Dynamometer type instruments are used as

ammeters and voltmeters, but their most valuable application is in wattmeters and energy meters.

Induction Instruments

Induction instruments are essentially dynamometer instruments in which current is fed into the moving system by induction or transformer action instead of by conduction through springs; for this reason they can be used only for alternating currents. They fall into three general classes, 1. Repulsion; 2. Shaded Pole, and 3. Double Pole Instruments. The first depends upon the repulsion effect discovered by Prof.

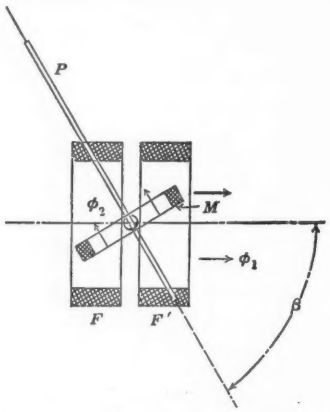


Fig. 13. Principle of the electrodynamometer instrument

Elihu Thomson, that a metal disc or ring is repelled from an electromagnet excited by alternating current.

The explanation lies in the fact that the magnet induces an e.m.f. in the disc or ring in quadrature with the magnetic field and consequently produce eddy currents in it. If these currents were in phase with the induced e.m.f. they would also be in quadrature with the magnetic field and there would be no resultant force but owing to the inductance and low resistance of the disc they lag behind the e.m.f. and, being out of phase with the field, produce a repulsion.

This principle permits of a simple method of measurement. In one application to that of an ammeter, the moving element consists simply of a thin aluminum or copper disc on a pivoted spindle. The edge of this disc is cut in the form of a cam and can turn in the gap of a laminated electromagnet. The current to be measured is passed through the coil of this magnet. The movement of the disc is opposed by the action of a spring and when at zero position, the entire pole face is covered by the disc. When the magnet is energized, the repulsion effect causes the disc to turn so that less of the pole face is covered by the disc. By suitably shaping the edge of the disc, a long and even scale can be obtained. In order to damp the movement of the disc, a permanent magnet is mounted on the other side of it, which retards its movements by the eddy currents induced. This method of damping is quite common and is used in a great many electrical instruments.

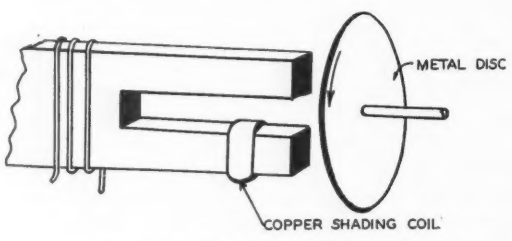


Fig. 14. Showing use of shading coil

The double pole type of instrument depends upon the torque produced upon a rotating disc, when the latter is mounted so as to turn across the face, or between the poles, of two electromagnets placed close together. If the two fields are in phase no torque is produced but if there is a difference in phase, a resultant torque is produced. This difference in phase may be secured in different ways; by shunting one of the magnets with a resistor or connecting it in series with a condenser. This principle is used a great deal in wattmeter and energy meters.

The shaded pole method referred to above is really an application of the double pole principle. It depends upon the fact that if the pole face, a single laminated alternating current electromagnet, is slotted, and one of the two pole faces so produced is encircled by a thick copper ring, the eddy currents induced in the ring by the magnet react on its field and cause the magnetism of that part of the magnet carrying the ring to lag behind that of the "unshaded" portion. This principle is shown in Fig. 14. By adding a spring pointer and damping magnet a very useful form of ammeter can be produced.

In the foregoing we have considered all the more common forms of ammeters and voltmeter principles as well as many principles also used in other electrical measuring instruments. It is difficult to classify electrical instruments in accordance with their purpose in measurement because as has been shown the same fundamental principles apply to many different instruments.

Hot wire and thermocouple type instruments were mentioned under galvanometers. These are equally adaptable as ammeters and voltmeters and are widely used in the measurement of high frequency alternating currents. Another type of voltmeter is the electrostatic type, which operates upon the same principle as the electrostatic galvanometer. These are independent of changes in frequency and wave form and may be calibrated with direct current. Commercial forms of this type are available up to about 200,000 v. Thermionic or vacuum tube voltmeters are special circuit arrangements using a vacuum tube and a microammeter. As shown in Fig. 17, the microammeter measures the change in plate current of a three electrode tube when the potential to be measured is applied between the grid and the filament of the tube. This arrangement is useful for measuring small alternating e.m.f.'s at any frequency.

E.M.F. Measurements

In addition to the various types of voltmeters already considered there is another class of instruments used in the measurement of voltage or electric potential. These are potentiometers. As its name implies, its primary function is the measurement of potential difference but it is equally applicable for the measurement of currents of any value when suit-

able resistance standards are available. In its simplest form its consists of a long uniform wire AB, Fig. 16, through which a constant current flows from a battery M. There is a fall of potential from A to B and the wire being uniform the fall of potential between two points is proportional to the length of wire or the resistance between the two points.

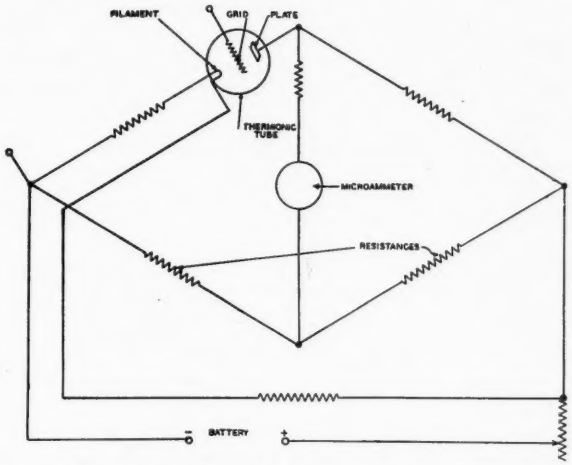


Fig. 15. Connection of the vacuum tube voltmeter

If two points A and C on the wire be joined to a galvanometer G, there will be a current through AGC, as shown by the deflection of the galvanometer. If we now introduce an opposing e.m.f., E_x, in the galvanometer circuit, and find the point C where there is no current in the galvanometer, we know that the fall of potential between A and C is equal to the e.m.f., E_x. In the same way we find a point D, such that the difference of potential between A and D is equal to the e.m.f., E_y, of a second galvanic cell.

Hence $E_x : E_y ::$ resistance AC : resistance AD
:: length AC : length AD

In this way two electromotive forces can be compared and by using a standard cell such as the Weston standard cell, of known e.m.f., we can thus measure any other e.m.f.

This simple form of potentiometer is called a slide wire potentiometer. If the wire is made of a definite resistance, say 2 ohms for a length of 1 meter and it is transversed by a current of 0.05 amp., then the total potential drop for 100 cm. is 0.1 volt or 0.0001 volts per mm. Further, if on the end of this wire any number of resistances, each of 2 ohms, are connected in series, each of them will have a drop of 0.1 volt which can be added to that of any section of the wire. This is the basis of the first accurate form of potentiometer devised by Prof. J. A. Fleming.

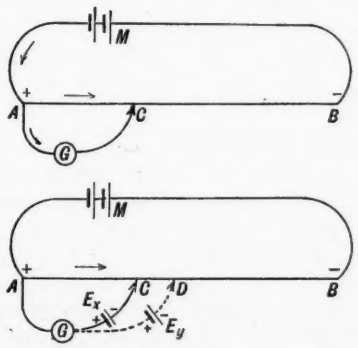


Fig. 16. Principle of the potentiometer

There are many different types and makes of potentiometers both for direct current and alternating current and while they vary considerably in their design and constructional details, the fundamental principle of operation is essentially the same in all of them. The wiring connections of a modern form of potentiometer is shown in Fig. 17. Here a resistance dial is combined with a slide wire. A special dial is also provided for the standard cell (at the left) and a separate pair of contacts for the standard cell e.m.f. so that no settings need to be disturbed when checking the potentiometer current.

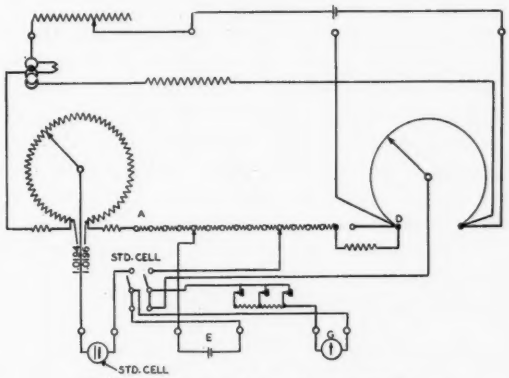


Fig. 17. Modern form of potentiometer

Alternating current potentiometers also are available. In order to balance two alternating potentials they must at every instant have the same frequency, wave form, amplitude and phase. The first two factors require that the voltages to be compared be derived, undistorted, from the same source. The amplitude of the voltage from the potentiometer can be varied at will, within limits, until equality is effected. The difference in phase can be eliminated either by using a phase shifter, by introducing a quadrature e.m.f. from a mutual inductor, into the balancing circuit or by using two separate potentiometers and supplying them with quadrature currents from a two phase supply.

Several other methods of measuring potential are available. For extremely high voltages, the sphere gap provides the standard method of measurement. This makes use of the fact that the maximum length of gap which for a given voltage will break down (spark over) depends on the maximum or "crest" value of the voltage wave. This crest value, however, is important since it is the value which determines the breakdown of insulators. Needle gaps were also used for this purpose for many years but they are unsatisfactory for very high potentials because of variations due to atmospheric pressure, humidity, etc.

Another form of high voltage voltmeter is the corona voltmeter which depends upon the fact that the point at which corona begins to form between a polished cylindrical metal rod surrounded by a concentric cylinder, is a function of the voltage and of course the size and shape of the rod and cylinder.

Power and Energy Measurements

Power in an electrical circuit is usually measured by wattmeters. Energy on the other hand is measured by watthour or integrating wattmeters. Since power is equal to the product of volts and amperes, the power in a circuit can also be measured by an ammeter, in series, and a voltmeter, in parallel, with the circuit. This is an extremely simple and effective method of measuring power, especially in direct current circuits and can be used in alternating current work also, provided the power factor of the circuit is known. For in alternating current circuits the power in watts is the product of the volts, the amperes and the power factor, P = E I x P F. Of course, if voltage and current are in phase the condition is exactly the same as for direct current circuits (i.e., unity power factor) and the power factor reading dispensed with.

The wattmeter, in measuring power directly, combines the elements of the voltmeter and ammeter in a single instrument as shown in Fig. 1. There are two general types of wattmeters in use, the "electrodynamometer type" for direct current work and the "induction type" for alternating current circuits. As shown in Fig. 1, the electrodynamometer type consists of two fixed coils and a pivoted coil free to turn within the magnetic field produced by the fixed coils. The fixed coils constitute the current or series element and are wound with heavy wire or strip. They are

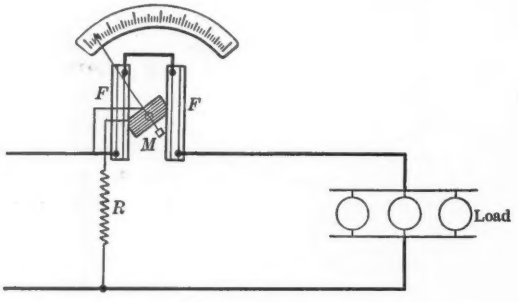


Fig. 1. The indicating wattmeter

connected in series and in series with the main circuit. The moving element is the potential or shunt element and is wound with a large number of turns of fine wire as in voltmeters and is connected in series with a non-inductive resistance across the main circuit.

An example of a widely used induction type wattmeter is shown in Fig. 2. The principle is the same as that used in the induction watthour (energy) meter to be considered later but instead of allowing the moving element to rotate, the torque is opposed by a spiral spring and hence the deflection is proportional to the power. It consists of three sets of windings, one set AA^1 being current or series coils, another SS^1 together with an adjustable resistance being the potential or shunt coils and a third set PP^1, which are compensation coils by means of which together with the adjustable resistance R the exact quadrative relation is obtained as in watthour meters. This type of instrument is also made in polyphase form by having two sets of current and potential elements acting on a common disc or drum. The double magnet principle used in this instrument was explained in connection with induction type ammeters and voltmeters.

There are other types of wattmeters such as the thermal wattmeter in which thermocouples are used to measure the difference in the temperatures existing in two resistors, and the electrostatic wattmeter but practically all indicating wattmeters are of the electromagnetic (dynamometer or induction) type. The electrodynamometer type wattmeter can also be used on alternating current if the power factor is unity.

The polyphase wattmeter was developed on the basis of the fact that the power on a two or three phase three wire supply could be measured by using two wattmeters and adding their readings together. This first resulted in the development of a double wattmeter with two similar moving coils at right angles, one below the other on the same spindle and with two similar sets of stranded fixed coils also at right angles so that the indications of the two systems were mechanically added together, and which could be balanced by torsion in the usual manner. Today deflectional direct reading polyphase wattmeters are made by many manufacturers. This principle is used with both the dynamometer and induction types as well as in watthour meters.

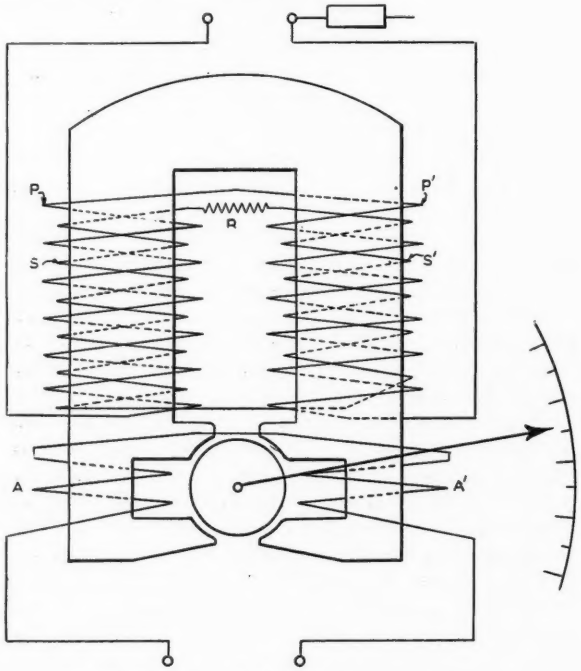


Fig. 2. Diagram of the induction type wattmeter

In a two phase four wire system, two single phase (or one polyphase) wattmeters are required. Each phase is measured separately and may be considered as two independent single phase systems. The total watts are equal to the sum of two readings. If both phases are balanced one wattmeter may be used and its reading doubled. For three wire, two phase systems the method and connections are the same as for three phase, three wire systems.

The most convenient method for measuring power in a three phase, three wire circuit is by means of the two wattmeter method referred to above and shown in Fig. 3. For this measurement either a single polyphase wattmeter may be used or two single phase wattmeters. The polyphase wattmeter consists of two single phase wattmeter elements connected to a common staff and pointer. For this reason it can be used as either single or polyphase circuits. The total watts indicated by this instrument give the algebraic sum of the two readings. The readings are correct for either a balanced or unbalanced system at any power factor.

The total power expended in a three phase, three wire system is the algebraic sum of these wattmeter readings. Care should be exercised that the instruments are connected correctly with regard to their polarities. The polarities shown in diagrams should be followed in order that the proper relation exists between the current and potential coils of the wattmeter. When the power factor of the system is above 50 per cent both wattmeter readings will be in a positive direction and the total power will be their sum. One of these readings will be larger than the other except at unity power factor for a balanced system, where both readings will be positive and equal. When the power factor of the system is below 50 per cent one of the wattmeters will indicate in the reverse direction (negative) and in order to get its reading its current circuit must be reversed. The total power in this case will be the difference of the two readings, the larger reading is always positive. At a power factor of 50 per cent, one wattmeter will indicate zero.

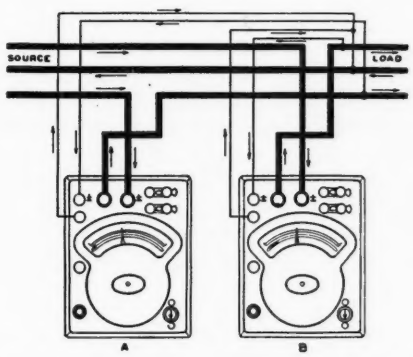


Fig. 3. Method of measuring power on 2 or 3 phase, 3 wire system

Three single phase or one single phase and one polyphase wattmeters are required to measure three phase, four wire power. The total power of the system is the algebraic sum of the readings of each instrument.

Energy Measurement

Electrical energy is measured by watthour meters or integrating wattmeters. Watthour meters are really nothing more than small motors whose speed is proportional to the power flowing in the circuit. The revolving element drives a registering mechanism on which the energy consumption is recorded. In wattmeters for use on direct current, the principle of the direct current motor is employed while those for alternating current circuits use the principle of the induction motor.

There are two classes of direct current watthour meters, the commutator type and the mercury motor type. The structural and electrical elements of a commutator type watthour meter are shown in Fig. 4. It consists of a moving element comprising an armature A, a commutator C, an aluminum disc D revolving between the poles of a pair of permanent magnets, all mounted on a steel shaft which drives a registering mechanism at the top. The shaft rotates in jeweled bearings. The armature revolves between the field coils F and is connected to the external circuit by means of very light silver tipped brushes which bear upon the commutator.

Stationary and movable coils are connected to the circuit exactly as are the stationary and movable coils of the indicating wattmeter, the field coils in series with the load and the armature across the load. The instrument is so constructed that the speed of its armature is proportional to the torque that drives it. Therefore, the rate of turning of the armature is proportional to the rate at which energy is delivered to the circuit. Hence, the total number of revolutions turned by the armature in a given time is proportional to the total energy expended in the load circuit.

In the foregoing it has been assumed that the torque which opposes the motion of the armature is proportional to the speed of the armature. In fact, however, this opposing torque may be considered as consisting of two parts: the torque required to overcome friction and the torque required to overcome the damping action of the magnets on the aluminum disc. The first part of this torque may be taken to be approximately constant while the second part is accurately proportional to the speed. Therefore, an arrangement for exerting on the armature a constant torque sufficient to overcome friction would largely eliminate errors due to friction.

This is accomplished by supplementing the main fields with an auxiliary field coil called a starting coil or a light load compensation coil connected in the armature circuit. So long as the e.m.f. between the mains does not vary the current in the starting coil is constant and it, therefore, exerts a constant torque upon the armature. If, however, the e.m.f. varies the torque due to the starting coil varies with the square of the e.m.f.

The Mercury Type D.C. Watthour Meter

The mercury type watthour meter consists essentially of a copper disc floated in mercury and subjected to a magnetic field perpendicular to its plane—upward on the right of the shaft in Fig. 5 and downward on the left. Current passing from left to right across the disc establishes clockwise rotation when viewed from above. The mercury serves the purpose of the brushes of the commutator and at the same time floats the entire moving system. F is a float which supports the shaft producing an upward thrust which is received by a jewel bearing at the top of the shaft. The disc constitutes a one turn armature and the requisite torque is obtained by enhancing the flux from the

voltage circuit electromagnet by means of an iron core. The disc if slotted radially is given an additional 50 per cent increase in torque.

In the commutator meter the torque to compensate for friction was produced by augmenting the field flux by means of a supplementary field coil energized by the line voltage. In the mercury meter the torque to compensate for friction is obtained in two ways. In the method shown in Fig. 5 a high resistance R is connected in shunt with the armature D and the potential circuit is completed by the sliding contact P. wound around the pole face of the voltage coil, or a "lag plate", is placed opposite the pole face. The current induced in this coil or plate will cause the flux to lag.

By varying the resistance of the coil or the position of the plate, the flux may be brought into exact quadrature with the voltage. The aluminum disc on which the actuating torque is produced also serves as the control by passing between the poles of permanent magnets, as in other integrating meters. In this way the errors due to temperature variations are elimin-

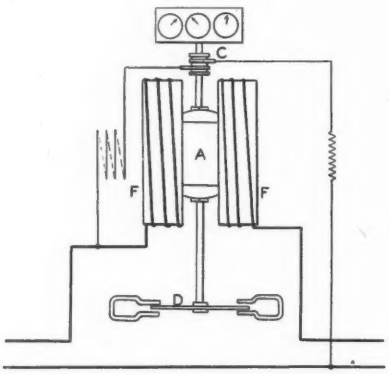


Fig. 4. Commutator type watthour meter

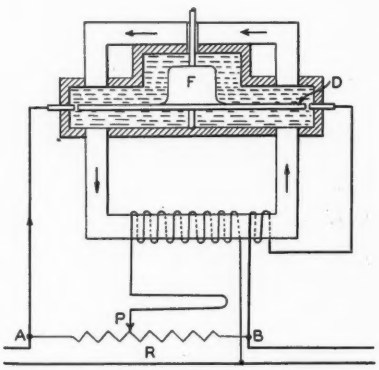


Fig. 5. Mercury type watthour meter

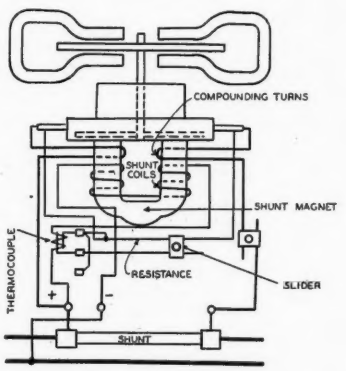


Fig. 6. Mercury type watthour meter with compensation

When the slider is at B practically all of the shunt current will pass through D because of the resistance R, thus adding to the torque. When the slider is at A, practically none of the potential coil current will traverse the armature.

In the second method, the circuit, consisting of two wires of dissimilar metals to form a thermocouple, is connected in parallel with the mercury chamber terminals. This couple is surrounded with a heating coil connected in series with the potential circuit. The e.m.f. generated in the thermocouple circulates a corrective current through the disc producing the necessary torque to overcome the friction of the disc at light load.

The Induction Type Watthour Meter

The induction type watthour meter used almost universally on a.c. circuits operates on the same principle as the induction motor. A laminated iron core is wound with a current coil of a few turns connected in series with the load circuit, and a highly inductive voltage coil having a different magnetic circuit is connected in parallel with the load. Each coil produces a flux which passes through an aluminum disc and induces eddy currents therein. Ideally the voltage coil is purely inductive, so that its flux is proportional to and in quadrative with the circuit voltage.

Flux of the current coil is proportional to and in phase with the circuit current. Hence, the resulting force on the disc is proportional to the product of the current by the inphase component of the voltage or to the power of the load, as in other watthour meters and in wattmeters. Since no circuit can be purely inductive, a short circuited phase compensating coil is ated, for a change in resistance of the disc with temperature affects the actuating torque and control torque.

The induction type meter has less friction than the commutator meter because of the lighter weight of the moving element and the absence of commutator and brushes. The friction torque is compensated by producing two slightly out of phase components of flux in the magnetic circuit of the voltage coil, thus producing a small driving torque dependent on voltage and independent of the load current. This may be accomplished by placing the phase compensating coil or lag plate in an unsymmetrical position which can be adjusted by trial. The arrangements of the electric and magnetic circuits and the methods of adjustment vary in different makes of meters.

As in the case of simple wattmeters, the energy in various types of polyphase circuits may be metered by a number of separate watthour meters, or by polyphase meters. The total load is the algebraic sum of the registrations of the two, three or more meters used. In ordinary practice it is more general to measure the load on polyphase circuits with polyphase watthour meters.

Generally speaking, polyphase meters have parts identical with those of the corresponding single phase meter, the principal difference being a larger core, two or more discs on one longer shaft and variations of internal connections. Three wire (single phase) and polyphase meters may consist of independent elements on the same shaft or of separate magnetic circuits linked with the same conducting disc.

The moving element in a polyphase watthour meter, naturally, is considerably heavier than that of a single phase meter and the friction torque cor-

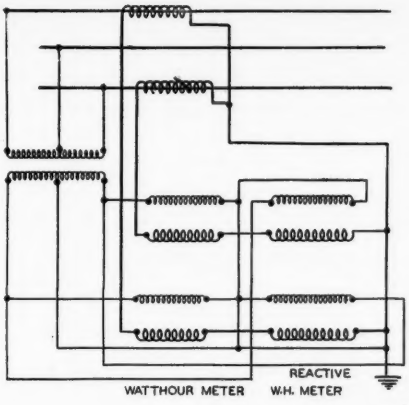
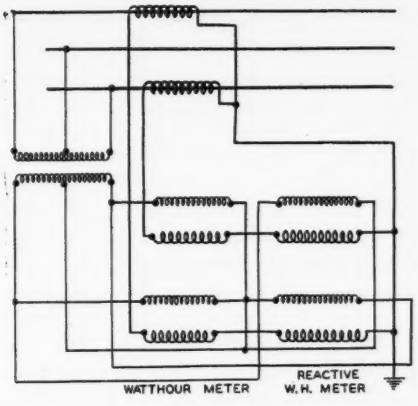


Fig. 7 (left) Connections for measuring active and reactive energy in a 2 phase, 3 wire circuit. Fig. 8 (right) Measuring the active and energy components in a 3 phase, 3 wire circuit



respondingly greater. This does not make the polyphase meter inferior to the single phase meter since the driving and breaking torques are also correspondingly greater.

One of the most important factors in the use of watthour meters is to be certain that the connections to the circuit are properly made. With single phase instruments the possibility of error is relatively small but with polyphase instruments the chance for error is considerable. A two element meter, for example, has four terminals for the current windings (two for each element) and four terminals for the voltage windings.

It is not likely that one of the current circuits will be open; this would mean either single phase functioning of the line or the existence of a short circuiting jumper around the meter or across one of the current transformers. Therefore it is necessary to recognize only the possibility of having either or both of the current connections reversed. This provides four situations, both correct, both reversed, one correct and the other reversed, and vice versa. Any one of these four situations (only one of which is systematically correct) may be associated with a multiplicity of situations arising in conjunction with the voltage connections.

The voltage connections may (1) be correct or (2) one of the voltage leads may be open circuited or (3) the voltage coil in the meter open or (4) the voltage transformer primary or secondary open or (5) two voltage leads from one element of the meter (or from one voltage transformer) connected to the same line wire. These situations in conjunction with the four current possibilities enumerated give 16 possible combinations only one of which, of course, will give the correct registration, i.e., that in which the voltage and current connections are closed correctly.

There are the further possibilities of having (6) one or both the voltage elements reversed and, in addition, (7) a 120 degree shift in phase of all the voltage connections. Dr. W. B. Kouwenhoven reported 30 equations for the registration resulting from all the possibilities outlined. Many of them result in utterly fantastic results at certain power factors but quite plausible results at other power factors.

It would be interesting to discuss the results of these many possible errors in detail and to indicate how the correct connections can be verified in each instance but this is beyond the scope of this article. For a complete discussion of this subject, the reader is referred to a recent book "Electric Power Metering" by Archer E. Knowlton.

Reactive Volt Ampere Hour Meters

When electric power is used at power factors below unity, the efficiency of operation and transmission is reduced as a consequence of the increased heating which results. The loss entailed varies as the sum of the squares of the active and reactive components of the current so that, at a power factor of 70.7 per cent, the losses produced by the idle reactive volt amperes (reactive power) are as large as those due to the active volt amperes. Some power companies, therefore, use energy rates with a factor which take the reactive volt ampere hour into consideration.

Measurement of reactive volt-ampere-hours is readily accomplished by meters which are generally ordinary watthour meters but in which the current coil is inserted in series with the load in the usual manner while the potential coil is arranged to receive a voltage at right angles to the load voltage.

In two phase circuits this is simply accomplished by using two meters as in ordinary energy measurement with the current coils connected directly in series with those of the active (watthour) meters but with the potential coils connected across the quadrature phases, as in Fig. 7. Merely interchanging the voltage leads between the outside wires and the voltage coils of the wattmeter in Fig. 3 will shift the indication from energy to reactive component.

In a three phase, three wire circuit the reactive volt amperes are most easily measured by two wattmeters connected as shown in Fig. 8. The current coils of the reactive watthour meter are connected in series with those of the active watthour meter. The potential coils are cross connected with respect to the current coils. With this arrangement the sum of the two readings is equal to 1.155 times the total reactive volt amperes with balanced load. To eliminate the necessity of making this correction in some instances autotransformers with unit point taps are used to obtain voltages of correct phase displacement and so making the meter direct reading.

Resistance Measurements

Most of the instruments used in the measurement of electrical resistance are of the comparison type; only a few give direct indications on a dial. The latter are called ohmmeters but in ordinary commercial practice are also known by various trade names such as "Meggers" or "Ohmers." All of them operate on principles based on Ohm's law—on the fact that given a constant difference of potential, the current through a circuit varies directly in accordance with the resistance.

To measure the resistance of any circuit, therefore, it is necessary only to have a voltmeter and an ammeter. By measuring the current in amperes and the voltage drop across the circuit the resistance of that portion of the circuit across which the drop is measused is given directly by Ohm's law, $R = E \div I$. If the resistance to be measured is comparatively small in value and if the voltage of the circuit is high, a resistance R_1 may be connected in series with the resistance to be measured, as shown in Fig. 1.

It is possible to measure a resistance by means of a voltmeter alone if the resistance to be measured is

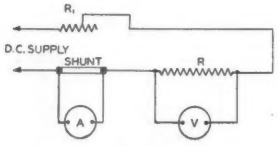


Fig. 1. Voltmeter and ammeter method of measuring resistance

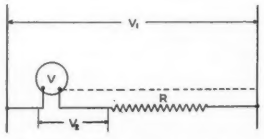


Fig. 2. Measurement of resistance by the voltmeter method

comparable with that of the voltmeter. In Fig. 2 let it be required to measure the resistance R. The voltmeter is first connected across the source of supply and a reading V_1 taken. It is then transferred so that the resistance R is in series with it across the source of supply and the voltmeter reading is again taken. Let this reading be V_2. As V_1 is the total circuit voltage and V_2 the voltage across the instrument, the voltage across the unknown resistance R is obviously $V_1 - V_2$. When the voltmeter is in series with R the same current i must flow through each, so the voltages are as follows:

$$V_2 = i\,R_v \quad \ldots\ldots (1)$$

$$V_1 - V_2 = i\,R \quad \ldots\ldots (2)$$

where R_v is the resistance of the voltmeter. Dividing (2) by (1) and solving for R,

$$R = R_v\,(V_1 - V_2) \div V_2 \quad \ldots\ldots (3)$$

This method of measuring resistance is of considerable use in determining the insulation resistance of motor and generator windings and of cables. Such resistances are, as a rule, very high so the result is expressed in megohms (1 megohm = 1,000,000 ohms). The equation (3) shows that the greater the resistance of the voltmeter R_v, the greater is the resistance that can be measured by this method. For this reason, special 150 scale voltmeters, having resistances of 100,000 ohms (1/10 megohm) are available. These give a sensitivity of some six times that possible with an ordinary 150 scale voltmeter.

The "Megger" which takes its name from the fact that it measures resistance in megohms, is an ohmmeter which indicates the resistance by the movement of a pointer over a calibrated scale.

The Evershed Megger

A cursory examination of Ohms law will show that as a galvanometer may be constructed with a fixed integral resistance to show the value of an e.m.f. in volts, so may it be constructed to operate on a fixed e.m.f. and show the value of an interpolated resistance

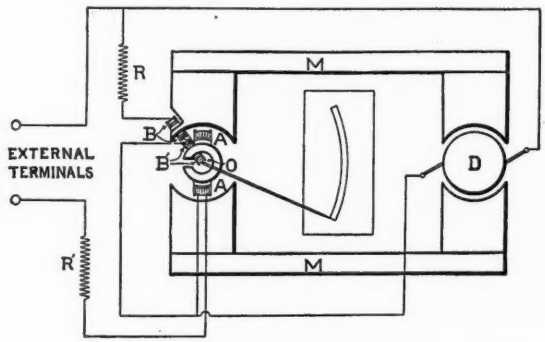


Fig. 3. The Evershed megger

in ohms. Provided the e.m.f. be kept at a fixed value, an ordinary voltmeter may be provided with a scale reading in ohms, as will be described in a later chapter.

It is often inconvenient to keep the e.m.f. at a constant yet practical value in a portable instrument. To obviate this the principle of the differential galvanometer is taken into account in the Evershed Megger. As will be seen in Fig. 3, the moving system of the Megger consists of a coil of insulated wire A connected in series with the armature of the dynamo D and by means of external terminals, in series also with the resistance to be measured. A pair of coils BB connected in series with each other and with a resistance but connected in multiple across the circuit of the dynamo are rigidly attached to the coil A and rotate with it. These coils are entirely free to move, being unrestrained by springs or gravity. The electrical connections are made by means of copper strips so as not to offer any restraining force to free movements. The needle or pointer which is actuated by the movements of these coils is therefore liable to rest at any point of the scale while the instrument is not in use.

Current being sent through the coils BB by means of the hand dynamo, causes the coils and the pointer attached to take up a position in the weakest part of the magnetic field. The pointer then indicates zero on the scale, or infinity.

Upon connecting an unknown resistance at the external terminals, the circuit through coil A, which was heretofore open, is now closed, having the unknown resistance in series with it. The current flowing through the coils now induces the latter to take up a definite position. This position indicated by the pointer on the scale is the resistance in ohms of the unknown resistance under measurement.

An increase in e.m.f. will increase the current through both coils to a proportionate extent, the ac-

curacy of the reading being thus practically independent of variations in the speed of the dynamo.

The Megger is dead beat, constant in calibration and does not deteriorate through any weakening of the magnets. A friction clutch interposed between the armature and the driving gear of the dynamo keeps the e.m.f. constant, invaluable when measuring insulations having considerable capacity.

Resistance Boxes and Wheatstone Bridges

Of the various methods used to measure electrical resistance, the most accurate is by comparison with a

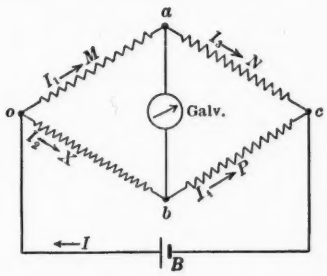


Fig. 4. Elementary Wheatstone bridge

known resistance. For this and for other purposes boxes of accurately adjusted resistances with convenient arrangements for connecting any number of them in series are used to a considerable extent. Two types in use are the plug and sliding contact types. In the former, the resistance coils are connected between brass blocks with hard rubber, or Bakelite tops are provided which on insertion into the tapered holes between the blocks short circuit the respective coils, so that the total resistance between the terminals is the sum of the resistance coils unplugged. In the sliding contact type, resistances are cut in or cut out by merely revolving a sliding brush over a circularly arranged set of contacts as in an ordinary rheostat.

Such resistances can be used in various ways but their principle use in the measurement of resistance is in the Wheatstone Bridge. For the measurement and adjustment of resistances, except those of very low value, the Wheatstone Bridge is the most convenient and accurate and the most commonly used device. It consists essentially of a resistance box, any of various types, to which is added a set of "ratio coils" which enables its resistance to be balanced or compared with any unknown resistance.

In its simplest form the Wheatstone Bridge consists of a set of known resistances, M, N, P (Fig. 4) and the unknown resistance X connected as shown. A battery is arranged to feed current into the two opposite corners o and c, while a galvanometer is connected between the other two corners a and b.

In making a measurement, the two arms M and N are each set at some fixed value of resistance, usually 1, 10, 100, 1000 ohms. The arm P is then adjusted until the galvanometer does not deflect. This shows that there is no current through the instrument and that the two points a and b are at the same potential. Furthermore the currents $I_1 = I_3$ and $I_2 = I_4$.

Without following through the mathematics of the relations involved it can be shown by simple algebra that

$$X = P\ (M \div N) \qquad (4)$$

which is the fundamental equation of the Wheatstone Bridge. The sides M and N are called the ratio arms and P is the balance or rheostat arm.

Wheatstone Bridges are made in a variety of forms. In most forms the resistances M, N and P consist of a number of resistance coils or units carefully adjusted to various multiples of 10 as mentioned above and so arranged that they can be conveniently connected in and out of the circuit by means of plugs or switches.

The slide wire bridge is one of the earliest forms of the Wheatstone Bridge, an extremely simple form in which balance is obtained by means of a slider which moves over a resistance wire. Such a bridge is shown in Fig. 5. If x is the unknown resistance, R the resistance at H, A the length between DC and B the

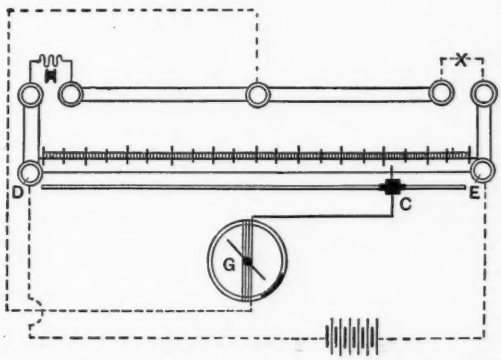


Fig. 5. The slide wire bridge

length between CE, then $R = (R \times B) \div A$. The precision of the slide wire bridge is a maximum when the sliding contact is at the center.

Measurement of Inductance and Capacity

As in the case of resistance, capacity and inductance measurements are usually made by comparison with fixed or variable standard condensers or inductances. Primary standards of inductance are usually single layer coils of copper wire wound with great care on non-conducting, non-magnetic cores which will not change in dimensions with time or with variation in temperature or humidity. Primary standards of capacitance are made with air as the dielectric, in which absorption and leakage are made nil by providing alternate plates with guard rings which receive the unavoidable absorption and leakage currents in the insulation required for mounting the plates.

Variable inductance standards or inductometers have two sets of coaxial coils wound on zones of spheres, the outer pair being stationary while the other pair rotates within it. When the rotating member is so set that all the turns of both coils are in the same direction, the inductance is a maximum; when it is set so that the turns of the rotor, oppose those of the stator, the inductance of the combination is a minimum. The windings of the two elements, of course, are in series.

Inductance standards for radio frequencies are made by winding single layer coils on open frames of

Bakelite using copper wire of small diameter and a minimum of varnish or other building material.

Inductance measurements are usually made by two methods: 1, null methods in which bridge networks are used and in which the unknown inductance is balanced against known standards, and 2, methods involving the computation of the inductance from measured values of impedance and power factor.

Modern bridge methods employ alternating currents but in early arrangements direct current was used. In the alternating current arrangement, the alternating potential is impressed on the bridge in practically the same way that the battery voltage is impressed on a regular Wheatstone bridge. A galvanometer or telephone receiver is used as a detector and the balancing resistance and reactance are varied alternately until a balance is secured. The circuits are similar to the conventional Wheatstone bridge arrangement, and while there are a great many different types available, fundamentally, they are the same. Inductance is not a quantity that is usually measured in ordinary power plant work, but it is well to understand the principles upon which inductance measurements are based.

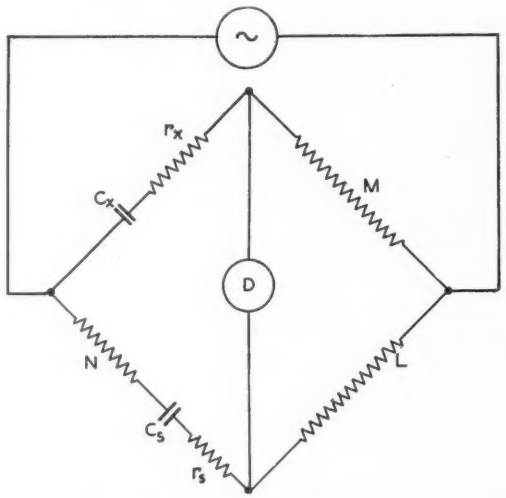


Fig. 6. A capacity bridge

Capacitance also is measured by either the null method or by the impedance method, as was the case with inductance. Alternating current is usually used but ballistic galvanometer methods using direct current are also available. Many different bridge arrangements are possible. A typical capacity bridge circuit is shown in Fig. 6. Balance is obtained by varying the resistance arm L and the variable resistance N in series with the standard condenser C_s and resistance r_g.

In the impedance method of measuring capacity, the reactance is measured with an ammeter and voltmeter using an alternating current of known frequency. The capacitance can then be calculated from the formula

$$C = 10^6 \, I \div 2 \, \pi \, f \, E$$

in which C = the capacitance in microfarads; I the current in amperes; f the frequency and E the voltage. A number of precautions must be observed in making use of this method. To begin with the voltmeter should be of the electrostatic type and its capacitance should be negligible in comparison with the capacity being measured. Next, the ammeter should be of the thermal type, free from inductance which might complicate matters by introducing resonance effects, and finally, the wave form of the alternating e.m.f. should be sinusoidal.

An extremely simple method of measuring capacitance is by means of the "microfaradmeter." To use this instrument it is only necessary to connect two of the four binding posts to a suitable source of alternating current and the other two binding posts to the capacitance to be measured, press the contact key and note the indication exactly as in the case of the voltmeter. This instrument has a moving system consisting of two coils set at right angles to each other and set to rotate between a pair of field coils. One of these movable coils is provided with two windings, one of which is connected in series with a standard comparison condenser and the other in series with the unknown capacity. The position of the moving system therefore depends on the relative capacities of the two capacities, the standard and the unknown.

The most simple method of comparing the capacity of condensers is by the direct deflection method using a ballistic galvanometer. If a condenser of capacity C is connected to a battery of e.m.f. it suddenly becomes charged with a quantity $Q = CE_1$ so that if two condensers of capacities C_1 and C_2 are connected successively to the same battery $Q_1 = C_1 E$, and $Q_2 = C_2 E$; thus $Q_2 \div Q_1 = C_2 \div C_1 = D_2 \div D_1$ where D_1 and D_2 are the corresponding swings of the ballistic galvanometer.

Measurement of Power Factor, Frequency, Synchronism

Indicating power factor meters belong to the class of instruments which may be designated ratio meters. The moving system of instruments of this class is without control, and can be considered as being acted upon by two or more torques, under the influence of which it takes up a stable position corresponding to the ratio required to be measured. In the case of power factor meters the ratio measured is that of reactive volt-amperes to actual watts, and the design of the majority of these instruments is such that the angle of displacement of the moving system from a fixed datum position is equal to the phase angle upon which the power factor depends. A power factor meter is thus more correctly known as a phase meter. The scale of the instrument is usually so marked that a direct indication of the cosine of the phase angle is given.

There are two general classes of power factor meters, (a) those operating on the electrodynamometer principle and (b) those based on the induction principle.

The simplest type of dynamometer power factor meter is one designed as a balanced two-phase circuit and a careful study of the principles of such an instrument will enable the action of the more complex types to be understood. The component parts of a two-phase

power factor meter are shown in Fig. 1. Two similar coils carrying the currents in each of the two phases of the system are set at right angles. The moving system consists of a pivoted coil the axis of which passes through the intersection of the axes of the fixed coils. The moving coil is provided with flexible ligaments which exercise a negligible control and by which the coil is connected in series with a non-inductive resistance, so that it carries a current proportional to, and in phase with, one of the line voltages.

A single phase power factor meter is built on the same general principle except that in this case the instrument has a single current coil and a double moving coil, the two members of this moving element being connected to the circuit voltage respectively in series with a resistance and a condenser or a reactance. A condenser is preferable as it gives a phase difference between the two currents in the moving system nearer to 90 deg. than can be obtained with a reactance.

One of the disadvantages of the dynamometer type power factor meter is the necessity for conducting wires to carry the current into the moving system. These conducting elements not only exercise a small control on the movement, but preclude the use of a 360 deg. scale, which is very desirable on circuits in which the direction of the current may reverse.

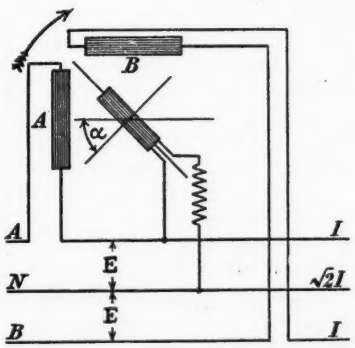


Fig. 1. Illustrating the principle of a two-phase power factor meter

These disadvantages are eliminated in the induction type power factor meter. There are several different types of induction power factor meters available but the principle involved in most of them is similar. In this type instead of a single moving coil, a Z-shaped pivoted iron vane is magnetized by a current in a fixed coil, which is proportional to and in phase with that which would flow in the moving coil of a dynamometer instrument. The plan of a three-phase type of induction power factor meter and the elevation, omitting two of the three vertical fixed coils are shown in Fig. 2. The three fixed coils carry the three line currents and the horizontal fixed coil energized by one of the circuit voltages magnetizes the pivoted iron which is free to rotate through 360 deg.

This type of meter is suitable only for balanced circuits, but it has found extensive application on alternator and rotary converter circuits where very approximately balanced conditions exist.

Of course in this consideration of instruments used for power factor measurement, it must be remembered that power factor can be determined simply from wattmeter, ammeter and voltmeter readings, by the relation $P\ F = P \div E\ I$ where P is the power in watts, E the e.m.f. in volts and I, the current in amperes.

The power factor in polyphase circuits in which the phases are balanced, is the same as that of the individual phases. When the system is unbalanced, the true power factor is indeterminate but for all practical purposes it is sufficiently correct to assume the power factor to be the average of the power factors of the separate phases. In a three-phase circuit the formula for determining the power factor from the wattmeter, voltmeter and ammeter readings is $P\ F = E\ I \times 1.73$.

Synchronism Indicators

Before connecting an alternator to the bus bars and in parallel with other alternators it is necessary not only that its voltage be the same as that of the bus bars but that it be in phase opposition as well. This is accomplished either by "lamps" or by synchroscopes. Lamps offer a simple and inexpensive arrangement but synchroscopes are more accurate and effective. The general principle involved in these instruments is the same as that of the power-factor meter, except two voltage elements are employed, instead of one voltage and one current element, and that no graduated scale is used, only the point of zero phase difference being marked. For the latter reason, a mechanical control, such as a spring, may be employed. One voltage element is connected to each of the generators to be synchronized. When the generators differ in frequency, the phase difference between their voltages is continually changing and the synchroscope pointer rotates continuously or in some makes, oscillates. When the frequencies are made the same, the pointer comes to rest at a position depending only on the phase difference, and when this is made zero, the pointer so indicates.

Commercial synchroscopes are of several types, some operating on the electrodynamometer principle, others on the soft iron vane principle, but their general principles are similar to those of the power factor meters already described.

Frequency Meters

The simplest form of frequency meter employs two voltage elements, one having a series resistor and the other, a series reactor. Since reactance varies with frequency while resistance does not, the relative currents of the two elements (which determine the indication) depend on the frequency. The electrodynamometer, soft-iron, and induction types of instruments are used in this general way as frequency meters. More elaborate arrangements of resistors and reactors are often used to cause a greater relative change in current with change in frequency. As apparent reactance varies with wave form, these instruments are somewhat subject to error due to wave distortion.

The vibrating-reed frequency meter is a type of instrument which is free from this shortcoming. It is reliable, and is not affected by wave distortion. It consists simply of a series of steel reeds that have successively different natural periods. These are placed

in an alternating magnetic field excited from the circuit whose frequency is to be measured. The reed having the same natural period as this circuit vibrates strongly, while the others are hardly affected. Usually the ends of the reeds are turned up and painted white so that the reed which is vibrating will be indicated by a white band or blur. A scale placed along the row of reeds is graduated to show their natural frequencies.

The question of frequency measurement is of course much more comprehensive than that which we have considered in this very general consideration of frequency meters. The types referred to are designed primarily for those frequencies used in ordinary elec-

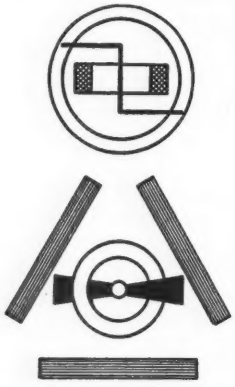


Fig. 2. The induction type power factor meter

tric power circuits. For high frequencies various other types are available, and in frequency "recorders," different principles are used. In one make of recorder, for example, a small synchronous motor drives a flyball rotor which in turn works a balancing lever controlling a relay recorder. Another recorder utilizes a bridge network with two ratio arms having a slide wire between them. The other two arms contain condensers, one with series resistance, the other with parallel resistance. For a small change of frequency the equivalent reactance of one arm is increased and the other is decreased and the movement of sliders to restore balance simultaneously brings the recording pen to a new position corresponding to the new frequency.

When dealing with extremely high frequencies such as those encountered in radio engineering simple types of frequency meters are possible. There are resonance type instruments consisting simply of a circuit containing inductance, capacity and some form high frequency current indicating device, i.e., a glow lamp or a thermo-galvanometer. When such a circuit is tuned to resonance by means of either a variable condenser or variable inductance, the galvanometer will indicate maximum current. When used in this manner this instrument is known as an absorption frequency meter since it absorbs energy (by electromagnetic induction) from the circuit in which the frequency is to be measured.

When such a circuit is provided with a means of generating sustained electric oscillations (thermionic oscillator) it can be used at a heat frequency oscillator and frequencies measured by "heating" the locally generated frequency with that of the circuit to be measured.

Special Electrical Instruments

In the foregoing we have considered only the fundamental aspects of the more common types of electrical instruments. Our treatment, therefore, has included only instruments of the indicating or direct reading type. Nearly all of the various class of instruments discussed, however, are also available in the recording type. Such instruments are essentially indicating instruments so arranged that a permanent, continuous record of the indication is made on a chart. In general the fundamental principles are the same as those of

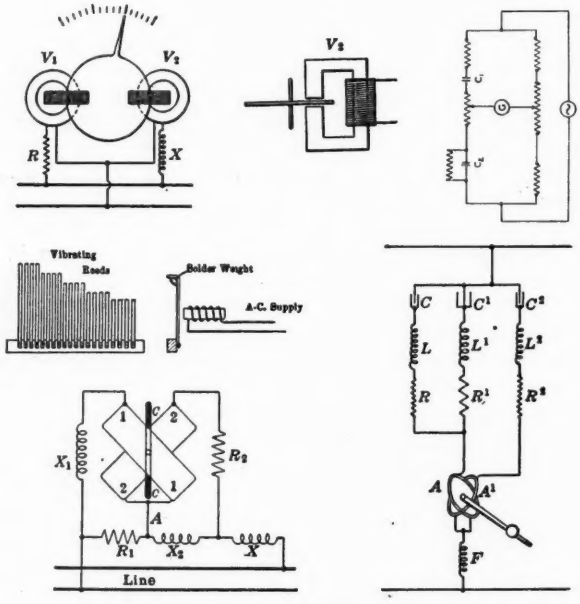


Fig. 3. Various types of frequency meters

standard indicating instruments with the addition of a suitable recording mechanism. There are two classes of recorders, however, one in which the record or chart is made directly by the moving element and those in which it is made by a separate mechanism. A clock, of course, is an essential part of all recording meters. Therefore such clocks have been of the conventional "spring" driven type, but in recent years with the perfection of the synchronous electric clock, this type is being used to an increasing extent.

Other factors have influenced recorder design in recent years. One of these is the development of the photoelectric cell and its associated vacuum tube amplifiers. Until these amplifying devices were available the recording meter always suffered in sensitivity compared to indicating instruments. This loss of sensitivity was a necessary consequence of the increased friction involved in the moving mechanism. The power available to operate most indicating instruments is very limited and unless some means can be provided for amplifying the movement of the mechanism, a considerable loss in sensitivity results. With vacuum tube amplifiers, however, especially in combination with photocell circuits, the slightest move-

ment can be amplified to any degree and when these elements are incorporated in the design of recorders, the resulting instruments are remarkably accurate and sensitive.

In some recording instruments where pen friction is particularly objectionable as in low reading millivoltmeters, the indicator is so arranged that it is in contact with the chart for only an instant at a time. In several forms of instruments, a metal rod presses the pointer in contact with the chart at certain times—several times per minute perhaps—the pointer being perfecly free in the interim. If the pointer carries an inked pen at its end or if the chart itself consists of a smoked chart, a succession of dots will be made. In some forms an inked ribbon is interposed between the pointer and the paper chart. An electric spark also has been used to puncture the paper chart as it passes under the pointer. In any case, however, the net result is the same. In other recorders, the slide wire potentiometer or slide wire bridge recorder is used with a high degree of success. It is used to record voltage, current, power, power factor, frequency, temperature, etc., with equal facility. The general principle consists in employing a sensitive D'Arsonval or electromagnet a.c. galvanometer as a detector in a suitable bridge or potentiometer circuit. When balanced conditions prevail the short galvanometer pointer stands under the tips of two right-angle levers which engage a mechanism for shifting simultaneously the recording pen and slide-wire contact. At regular intervals, every five or ten seconds, a motor driven mechanism lifts the galvanometer-needle-tip.

There is another class of instruments which is extremely useful in the study of transient conditions or rapidly fluctuating conditions, namely the oscillograph. The oscillograph is an instrument which gives a graphical record or a visual indication of the manner in which a rapidly changing current or voltage varies with respect to time.

Though the fundamental principle of the oscillograph is comparatively simple, in its structure and operation it is a very complex instrument, requiring care and expert knowledge in its use. In recent years their construction has been considerably simplified and compact portable forms are available which are practically foolproof. The current measuring elements used in oscillographs partake of all the types already considered. The moving iron, moving-coil, string and electrostatic galvanometers have all been adapted for use in the oscillograph. More recently the cathode ray tube has been commercially adapted to the oscillograph. No attempt will be made here, either to describe all the various types of oscillographs or to discuss their use. It is sufficient to state that by means of these instruments visual indication or photographic records can be obtained of transient phenomena having frequencies up into the millions of cycles per second.

Straws in the 1935 Wind

GATHERED as deductions from talks by various leaders in the government at Washington, before the National Conference of Business Paper Editors, probable moves in the near future may be expected about as follows:

With the exception of capital goods industries, business is thought to be on the road to recovery and Government is inclined, at least temporarily, to allow business an opportunity to make good, with greater freedom and independence than in the past months. Those in charge of the Government program expect "reasonable prosperity" to return by fall of 1935 or spring of 1936.

It is felt that the worst of labor troubles are over and that they will diminish, although small disturbances may arise from time to time. As has been evident, the Administration favors labor but the A. F. of L. is said to have lost considerable influence in Washington. Some plan of unemployment compensation will be passed but probably not Federal old-age pensions, nor any 30-hr. week legislation.

Next spring a big spending spree on public works will probably begin, intended as a final priming of the industrial pump, with the hope that this will start the flow of natural productive facilities. Large scale housing plans and some assistance for durable goods industries will probably be included. The FHA is felt to have succeeded well in starting modernization of homes, but corporations have not responded as well to modernization stimulus. RFC may make loans for modernization as well as for working capital. Loans from RFC, FHA and HOLC are being paid back bit by bit and their managers seem to feel that few losses of capital may be incurred, though defaults may eat up interest.

NRA is likely to be modified, the effort being to remove unworkable provisions and reduce code activities to a sound basis for operation, if possible. AAA will likely be continued with processing taxes, limitation of output and provision for holding land idle. Higher taxes are sure to come, but will probably be delayed until 1936 to give industry a chance to start recovery. When increase comes, corporation surpluses are liable to be raided, hence there may be considerable distribution in the form of dividends to avoid having the surpluses appropriated into the U. S. Treasury by taxation.

The Administration's determination to bring about public operation of utilities has been evident for a long time, hence new power projects to harass the power companies may be expected. The blunders in TVA, which are generally admitted, may be avoided in new developments but it is not thought that they will stop the Administration from proceeding on the course it desires.

Direct currency inflation is not now contemplated but credit inflation by the issue of bonds against which currency may be issued will continue and probably the effort will be made to gain further control of the credit system through the Federal Reserve System and the banks allied to it.

These conclusions are not the statements of any one or of several government officials, but were reached after listening to talks by a number of representative men who might be expected to reflect the belief and intent of the new dealers. Since present trends seem to indicate that they will be in control until 1940, the conclusions are worth study as markers for laying out a course for the years until then, at least.

Plant

Turbine and boiler control panels at Bremo Station

INSTRUMENTS in a power plant when ideally chosen and properly distributed may be compared to the nervous system of the body, for they give to the governing head information on conditions and warnings of danger that insure the most satisfactory operating service. Instruments of the operating class may render service in three ways, namely, by indicating or giving warning of approaching dangerous conditions, by indicating or totalizing quantities necessary for accounting purposes, and by furnishing information by means of which highest operating efficiency can be maintained.

The whole question of instrumentation is, in the last analysis, one of economics. There is almost no end to the amount of money that may be spent for operating instruments and unless the operating staff is sufficiently trained in the interpretations of the instrument readings, their value to the plant is greatly reduced. In the hands of experts, however, instruments have paid big dividends in the way of savings in fuel, supplies and repairs. The greater such expenses run in a plant, which ordinarily means the larger the plant, the greater the opportunity for saving through the intelligent use of instruments.

From an investment standpoint, many designing engineers consider that it is better to install too few instruments than too many and this attitude has been reflected in the low operating efficiency obtained in plants that are fast becoming obsolete. Without doubt, operating instruments that are not kept in repair or are not used by the men in charge of the equipment are not only a waste of invested money but have a bad effect on the morale of the operating force. A more intelligent class of operators, however, is being employed in power plants today than in years past which insures a better understanding of the services instruments can render a power plant, also a desire to keep the installed instruments in the best possible condition. Nevertheless, no hard and fast rules can be laid down for the choice of operating instruments since so much depends upon the class of operating engineers, the size of the units and the service the plant performs. In regard to the size of units it may be stated that the number, investment cost and upkeep costs of instruments increase with the size of the units but not proportionately, so that these costs per kilowatt of unit capacity tend to decrease with the increasing size of the unit. This proportion of decrease is not the same, however, it being more rapid with investment costs than with upkeep.

In a report of the Prime Movers Committee of the N.E.L.A., the suggestion was made that the minimum number of instruments advisable in a steam power plant are: Steam pressure gages on boilers, header and turbine throttle; feedwater pressure gage; mercury column on turbine exhaust; thermometers for feedwater, steam temperature (if superheated), and bearing oil. In addition, the usual electrical instruments—voltmeters, ammeters, wattmeters—should be provided, also kilowatt-hour meter to give net output from plant and means for fuel measurement if the size of the plant permits. Any additional equipment, it was stated, should be installed only as the investment is justified.

This list, given as a minimum in the smallest size plant, will be recognized as those necessary for reasonably safe operation and arriving at the fuel cost of producing power. It gives no aid to the engineer in improving the efficiency of the plant nor insuring the continuity of service. For a plant with one or two large generators and several boilers of 1500 hp. the committee suggested the following list as typical of what might be expected in the average central station:

Turbine Room Instruments

(a) Indicating steam gage at throttle and other points, depending upon the type of turbine or engine; mercury column; thermometers for steam temperature (if superheated) and bearing oil; indicating wattmeter; barometer (Aneroid type may be used if frequently checked).

(b) Thermometers for circulating water inlet and discharge and condensate.

(c) Device for measuring air leakage where possible.

Operating Instrument Equipment

Safe and Efficient Operation of Power Plant Equipment Involves an Intelligent Interpretation of Conditions Indicated by Instruments Carefully Selected, Installed and Maintained

(d) Steam flow meter or condensate meter.

(e) Device for measuring tube leakage.

Boiler Room Instruments

(a) Steam gage on each boiler (where uniform steam pressure is important and difficult to maintain a large master steam gage on header is desirable).

(b) Feedwater pressure gage.

(c) Draft gages at uptake, over fire and air pressure gages in air duct and at those points of the stoker required by that particular point.

(d) Steam flow meter on each boiler.

(e) Air flow gages or CO_2 recorder.

(f) Load indicator or total flow steam meter.

(g) Feedwater thermometer.

For Checking Operation

(a) Kilowatt-hour meters and coal scales; steam pressure (and temperature) recorders.

(b) Boiler feed temperature recorder.

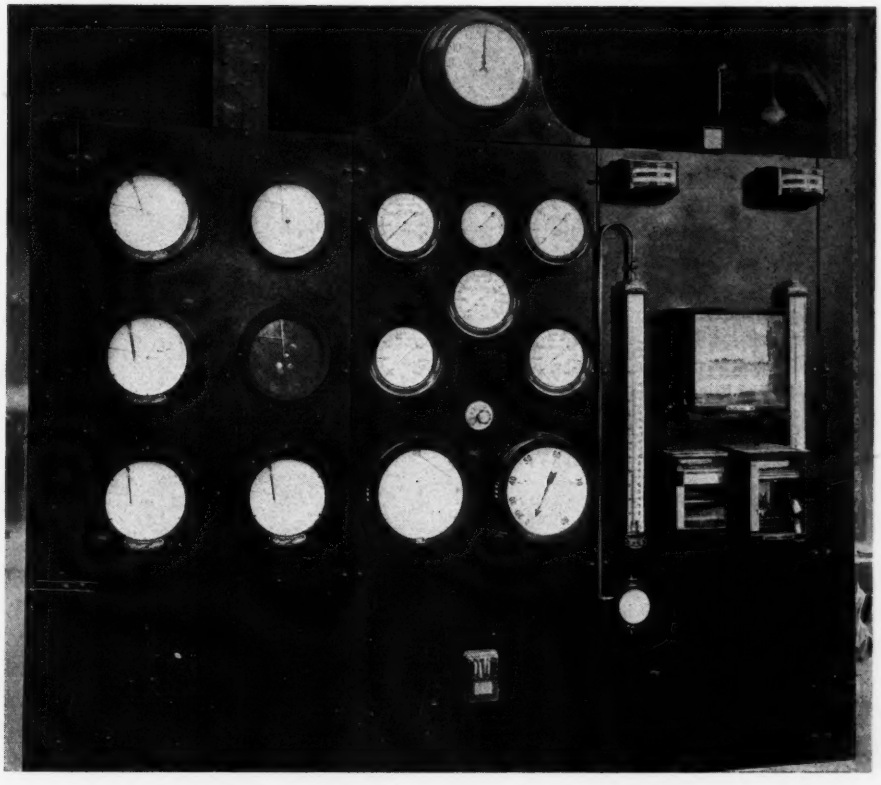
(c) Vacuum recorder; steam flow meter or feedwater meter or both; blow-down meter (where this is impractical a recording thermometer placed in a blow-down line indicates frequency of blowing and leakage of blow-down valves).

(d) Feedwater pressure recorder.

(e) CO_2 recorder; flue temperature recorder.

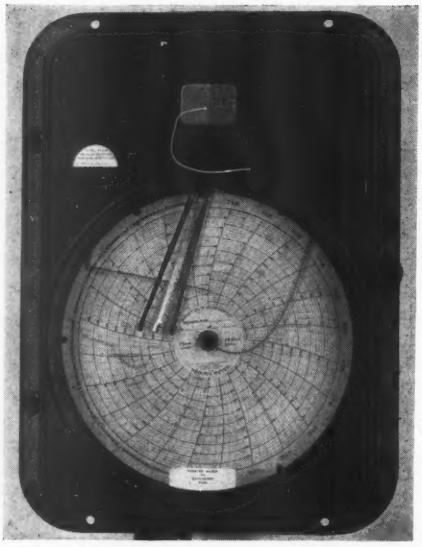
While such lists are helpful, the problem of instrumentation is far more complicated than merely naming instruments to go into the plant. Each piece of equipment in the plant has peculiarities of its own that require more or less of the operator's attention which may be greatly relieved if carefully chosen instruments are provided for that unit. As a rule the necessary instruments for such equipment are indicated by the manufacturer who wishes his equipment to give proper service but the plant designer must decide on the type and make of instruments that indicate surrounding conditions. In many cases these instruments are installed after the equipment has been in operation and the need for them has been indicated by accidents or low efficiency.

Safe operation is the first thing to consider in selecting instruments. Any condition, whether it is



Turbine room instrument panels typical of present practice

Easily read indicating instruments are located on the center panel and at such a height as to make them most visible features of the board. Recording instruments are easily accessible for changing charts and so located as to be instantly checked against the indicating instruments, while the electrical instruments, vacuum manometer and barometer on the panel to the right are conveniently assembled to give the operator a picture of conditions



Photo, Bristol Co.

Fig. 2. Combined meter that records pressure, temperature and flow on one chart and integrates total flow

Instruments used for accounting purposes logically come in for second consideration. They have to do directly with costs of producing the services rendered by the plant and deal in material or load quantities such as fuels, water, steam, compressed air, electricity, refrigeration or mechanical power. Such instruments are of the totalizing type giving quantities that pass between times of meter readings. The readings from these meters are what go to make up the monthly reports to the business department but can also be of great aid to the operating force in reducing costs and increasing efficiencies.

The third type of instruments has for its purpose the increasing of efficiency, reliability, life of equipment and quality of service and may be appropriately termed efficiency instruments. They may be indicating, recording or totalizing in the manner of imparting information, they may be permanently installed in the most convenient location, or portable and used intermittently for checking purposes or they may be of the laboratory type used in routine analyses of fuels, water, oils, instrument calibration or work of like character. This class of instruments is of value only from an economic standpoint and they can be

Fig. 4. Individual instrument panels in well equipped stoker fired plant

controllable or not, to which the equipment may be subjected in normal or even abnormal operation, should be given careful thought to determine to what extent it influences the safe operation of the unit and how far a knowledge of this changing condition would go toward averting accidents or even interruption of service. An instrument may be the only or best way to impart a knowledge of such conditions to the operator and should be provided where it will be of greater service.

Pressures, temperatures, speeds, loads, voltages, amperage are all conditions that can create injury to operators and damage to equipment if they go beyond design limitations, and instruments are the only accurate means operators have of knowing the proximity to these dangerous conditions. The likelihood of dangerous conditions occuring, however, is a question to be decided in each different plant. The plant design may permit the use of one instrument to safeguard a number of units thus cutting down investment costs.

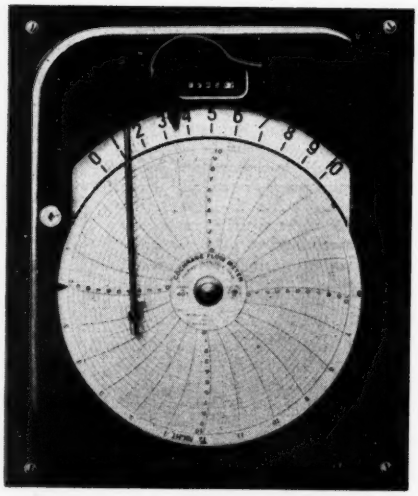


Fig. 3. Flow of the liquid is indicated, integrated and recorded by this meter

Photo, Cochrane Corp.

Instruments to Be Considered for Operating Purposes

Steam Generating Unit	Large	Medium	Small	
Pressure gage - Steam				
Boiler front	I	I	I	S & E
Control board - superheated	I & R	I & R	R	
- saturated	I & R	I		
Pressure gage - Water				
Feedwater pipe - high side of regulator	I	I	I	S
- low side of regulator	I	I		
Control board - Feedwater header	I & R	I & R	R	
Water level gage				
Boiler front - gage glass	I	I	I	S
- water column try cocks	Hand	Hand	Hand	S
Control board	I & R	I		
Draft gage				
Boiler setting - differential	I	I		E
- 3 point			I	E
Control board - 3 to 8 point	I & R	I & R		E
Feedwater meter				
Special meter board	I R & T	I R & T	I R & T	E & A
Control board	I R & T	I R & T		
Steam flow meter				
Boiler front	I			
Control board	I R & T	I R & T	I R & T	E & A
Air flow meter				
Control board	I & R	R		E
Temperature instruments				
Steam - superheated	R & I	R & I	I or R	S & E
Feedwater - economizer inlet	R	R	R	E
- boiler inlet	R	R	R	E
Preheated air - preheater inlet	R	I		E
- furnace entrance	R	I		S & E
Flue gas - leaving boiler	R	R		E
- leaving economizer	R	R		E
- leaving preheater or in breeching	R	R	I	E
Fuel scales	T &	T & R	T	A & E
Fuel oil or gas meters	T & R	T & R	T	A & E
Blow off water meter	T	T		E
or thermometers	R	R		E
Flue gas analysis				
CO_2	R	R		E
CO	R			E
Orsat	P	P	P	E
Smoke detector	I & R	I	I	E
Boiler water analyzer	P			E & S
Feedwater analyzer	P	P	P	E
Dissolved oxygen meter	I & R			S

Steam Turbines Driving Generators	Large	Medium	Small	
Pressure gages				
- Steam at h.p. throt.	I & R	I & R	I & R	S & E
- Steam at I.p. throt.	I	I		S & E
- Steam at L.p. throt.	I	I		S & E
- Steam at exhaust	I	I	I	S & E
- Steam at bleed points	I	I	I	S & E
- Oil to governor	I	I	I	S
- Oil to bearings	I	I	I	S
- Water to bearings	I	I	I	S
Mercury Column - Vacuum	I	I	I	
Barometer Mercurial - Atmospheric air	I	I	I	
Thermometers				
- Steam at throttle	I & R	I & R	I & R	S & E
- Steam at exhaust	I & R	I & R	I & R	S & E
- Main bearings	I	I	I	S & E
- Lubricating oil	I	I	I	S & E
- Bearing water	I	I	I	S & E
Speed Indicator Tachometer	I	I		S
Steam flow meter	I,T & R	I,T & R	I,T & R	A & E
Load indicator - Watt-hour meter	I,T & R	I,T & R	I,T & R	A, S

Condensing Apparatus	Large	Medium	Small	
Pressure and vacuum gages				
Manometer at exh. inlet or Bourdon gage	I & R	I & R	I	E
Circulating water inlet	I & R	I	I	
Steam to auxiliaries	I	I	I	S
Barometer - mercurial or absolute pressure gage				
Atmospheric air	I & R	I	I	E
Thermometers				
Exhaust steam	I & R	I		E
Condensate	I			E
Circulating water inlet and outlet	I & R	I	I	E
Meters				
Condensate	T			
Circulating water	T	T		E
Air meter	T			E
Power consumed				
Motor driven aux. - Wattmeters	T	T		A & E
Steam driven aux. - Steam flow meters	T			A & E
Leakage recorder	I			E

Generators	Large	Medium	Small	
Voltmeters - Main generator	I & R	I & R	I & R	S
- Exciter	I & T	I & T	I	S
Ammeters -				
Each phase	I & R	I & R	I	S
Exciter circuit	I & R	I & R	I	S
Wattmeters -				
Main generator output	I T & R	I T & R	I T & R	A S & E
Exciter output	T			E
Power factor meter	R	R	R	E
Synchroscope	I	I	I	S
Temperature coils				
Armature	I			E & S
Field	I			E & S
Thermometers				
Bearings	I	I	I	E
Cooling air or gas	I			E
Tachometer or Frequency meter	I & R	I	I	E
Pressure gage				
Bearing oil	I	I	I	S

Reciprocating Steam Engines	Large	Medium	Small	
Pressure gage				
Steam	I	I	I	S
Receivers	I			E
Exhaust (low pres. or vacuum	I & R	I	I	E & S
Lubricating oil	I	I		S
Speed indicator				
Tachometer or frequency indicator on direct connected generator	I I & R	I & R	I & R	S
Thermometers				
Exhaust steam	I	I		E
Main bearings	I			S
Steam flow meter	I T & R			E
Load indicator - Wattmeter	I T & R	I T & R	I & T	S & A

Diesel Engine Direct Connected to Generator	Large	Medium	Small	
Load indicator Wattmeter	I T & R	I T & R	I T & R	S, A
Speed indicator Tachometer or frequency meter	I & R			S
Pressure gages				
Fuel oil	I	I	I	S & E
Lubricating oil	I	I	I	S & E
Cylinder cooling water	I	I	I	S & E
Exhaust gases	I	I	I	S & E
Spray air pressure	I	I	I	S & E
Scavenging-air	I	I	I	S & E
Starting air	I	I	I	S & E
Temperature Thermometers				
Cylinder cooling water in and out	I	I	I	S & E
Lubricating oil	I	I	I	S & E
Exhaust gas, multi point	I	I		S & E
Fuel oil	I	I		S & E
Atmospheric air	I	I		S & E
Fuel oil meter	T	T	T	A & E
Barometric pressure	I	I	I	E
Lubricant meter	T	T	T	A & E

Hydraulic Turbines Driving Direct Connected Generators	Large	Medium	Small	
Load indicator Wattmeter	I T & R	I T & R	I T & R	S & A
Speed Indicator				
Tachometer	I & R	I & R	I & R	S
Frequency meter	I	I		S
Pressure gage Head water	I & R	I & R	I & R	E
Tail water level	I & R	I & R	I & R	E
Thermometers				
Water entering turbine	I & R	I & R	I	S
Main bearings	I	I	I	S

I = Indicating
T = Totalizing
R = Recording
P = Portable
S = Safety
A = Accounting
E = Efficiency

made to pay for themselves and their upkeep only through the savings they accomplish. As indicated previously, such possibilities become greater as the size of the plant increases.

Needs of Each Unit Considered

An approach to this problem involves consideration of each important unit of equipment that is to be installed in the plant; its relative position in the plant; its connection by piping, ducts, electric wiring or shafting to other equipment; the extent and importance of the service it is expected to render; and the limiting operating conditions for which it is designed. With this in mind the accompanying tables have been prepared, listing instruments which have been found of use in the operation of the equipment for which the list appears.

These instruments have been chosen because of their assistance to the operating staff in maintaining safety to operators and equipment, gathering cost data, and maintaining the highest possible efficiency. The suggestions of the choice of instruments made here for large, medium and small plants are based on information gathered from numerous plants of modern design but are not to be considered as specific recommendations since local conditions must always be considered. In each case, the instruments listed, however, should be given consideration.

Instruments to be considered for testing purposes are treated in another article in this issue and are not included in this tabulation of operating instruments. The particular make of instrument selected must be left to the judgment of the engineer but material assistance in determining upon types is given in previous pages of this issue.

Some comment on the instruments listed may be timely as giving a basis upon which these instruments are suggested, although it is manifestly impossible to give all the advantages of each instrument in this discussion.

Three general methods are employed in power plants to impart instrument readings to attendants, i.e., direct indications, graphic recording and totalized figures. Indicating instruments give instantaneous readings either on dials, scales or by color changes. They are of immediate value only, unless the readings are noted in the operating log sheet of the plant record

Instruments to Be Considered for Operating Purposes (Cont.)

Feedwater Heaters

	Large	Medium	Small	
Pressure gages				
Steam to heater	I	I		E & S
Water to heater control valve	I	I		E & S
Thermometers				
Steam inlet	I & R	I		E
Water inlet (make up)	I & R	I		E
Water inlet (condensate returns)	I & R	I		E
Water outlet	I & R	I & R	I or R	E
Condensate (if closed heater)	I & R	I		
Vapor exhaust	I	I		
Water meters				
Makeup water	I T & R	T	T	E & A
Return hot condensate	I T & R	T	T	E & A
Steam meters				
Steam flow - Bleed heaters	I T & R	I T & R		E & A
Gage - water level	I	I	I	S

Fans

	Large	Medium	Small	
Pressure gages				
Intake	I			E
Discharge	I	I	I	E
Temperature				
Intake	I	I	I	S
Bearings	I			S
Speed				
Tachometer	I			
Power used				
Motor drive - Watt-hour meter	T	T	T	A
Flowmeter	I T & R	I	I	A

Refrigeration System

	Large	Medium	Small	
Pressure gages - refrigerant				
Compressor suction	I & R	I & R	I & R	S & E
Compressor Intermediate	I	I		S & E
Compressor Discharge	I & R	I & R	I & R	S & E
Steam if engine driven				
at throttle	I & R	I or R	I or R	E
at exhaust	I & R			E
Thermometers				
Compressor suction	I & R	I & R	I	S & E
Compressor discharge	I & R	I & R	I	S & E
Compressor main bearings	I	I		S
Compressor jacket water	I			
Condenser water supply and discharge	I	I	I	E
Brine tank discharge and return	I	I	I	S & E
Meters				
Liquid refrigerant pumped	T	T		E
Condensing and cooling water	T			E
Power consumed				
Motor drive - Wattmeter	I & T	I & T	T	S,A & E
Hydrometer - Brine density	I	I	I	E & S

Pumps - Centrifugal, Rotary and Power

	Large	Medium	Small	
Pressure gages				
Suction	I	I	I	E
Discharge	I	I	I	E
Thermometers				
Suction	I	I	I	S
Bearings	I			S
Flow meters				
Discharge	I T & R			A
Speed indicators				
Tachometer or Revolution counter	I			A
	T			A
Power used				
Kilowatt hour meter	T	T		A

Motors

	Large	Medium	Small	
Wattmeter	T	T	T	E & A
Voltmeter	I	I		
Ammeter	I	I	I	S
Power factor meter	I			E
Thermometers - Bearings	I			S
Resistance thermometer Armature and field winding	I			S

Displacement Compressors and Blowers

	Large	Medium	Small	
Pressure gages				
Suction	I			
Intermediate	I			
Discharge	I & R	I	I	E
Cooling water	I	I	I	E
Barometer				
Atmospheric air	I			
Thermometers				
Suction	I	I		E
Discharge	I & R	I		E
Cooling water to jacket and intercooler, inlet and outlet	I	I		E
Main bearings	I			E
Power meters				
Motor driven - Wattmeters	T	T	T	A & E
Flow meter	I T & R	T	T	A & E

I = Indicating
T = Totalizing
R = Recording

P = Portable
S = Safety
A = Accounting

E = Efficiency

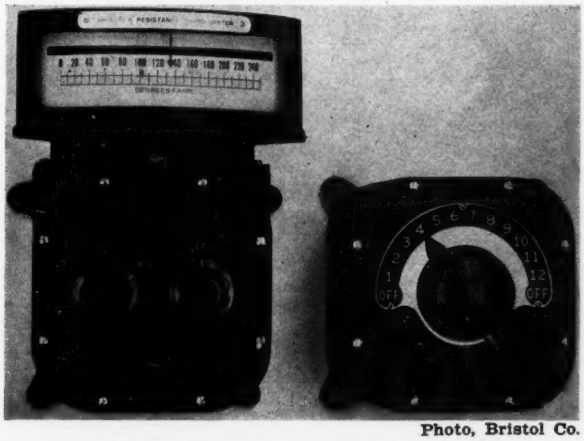
system. It is essential therefore that they be of sufficient size and so lighted and situated that they can be read at a glance by the attendant from positions he occupies in his routine work.

Graphic recording instruments make permanent records on scaled strips or circular charts of all variations in the condition registered, the position of the curve indicating not only the numerical value of the condition but the time, as the chart is moved uniformly by clock mechanism. This type of instrument relieves the operator of the necessity of reporting readings on the log sheet and they have their value where the number of employes is limited or the service conditions are exacting. In many cases the recording instrument may serve also as an indicating instrument if the position of the recording pen is plainly readable.

Totalizing instruments may accomplish their purpose by one of two methods, the simpler being by means of a counting or adding mechanism, the other integrates areas under the recorded curve on a chart and summarizes them to give accumulated quantities of the instrument readings to be recorded either automatically or by the attendant. These instruments are necessary for obtaining data for the accounting department and for calculating the efficiency of the unit. Indicating, recording and totalizing may be incorporated in one instrument or several related records may be drawn on one chart giving a convenient means for studying changes in operating conditions.

Instruments for Steam-Generating Units

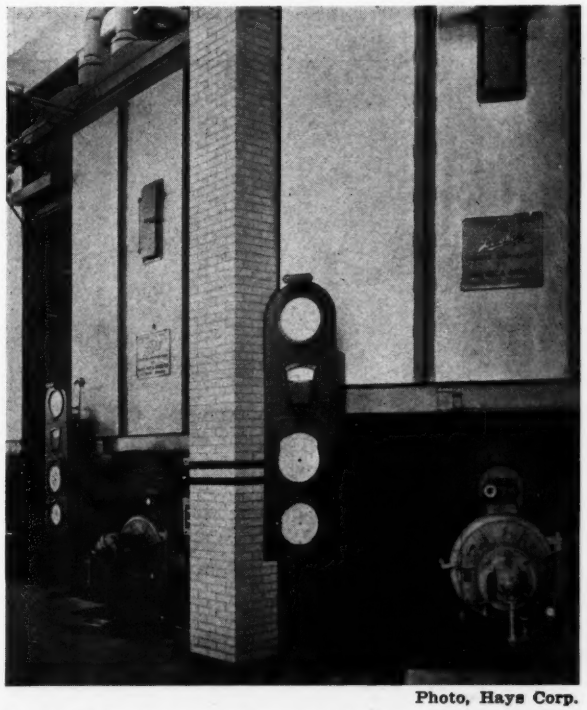
Steam and water pressure gages on boilers are essential to the safe operation of the unit and they should be located in the most convenient place for the operator, commonly the front of each boiler at the center for the steam gage and at the side for feedwater gage. Where control boards are installed more elaborate instruments may be used such as indicating and recording or recording only, with pen position plainly visible, these, however, should be in addition to those installed for safety purposes on the boiler. Indicating pressure gages should have dials large enough to be easily read by the operator from his usual working position.



Photo, Bristol Co.

Fig. 6. Indicating pyrometer convenient in securing temperatures from a number of points

The water level gage is also extremely important from the safety standpoint and every provision available should be made to avoid a mistake in reading the boiler water level. The gage glass is of first importance but for checking purposes trycocks on the water column are required by the boiler construction



Photo, Hays Corp.

Fig. 5. Indicating steam pressure and draft, recording steam flow and combustion conditions this compact panel is an aid to attendant of the oil fired boiler

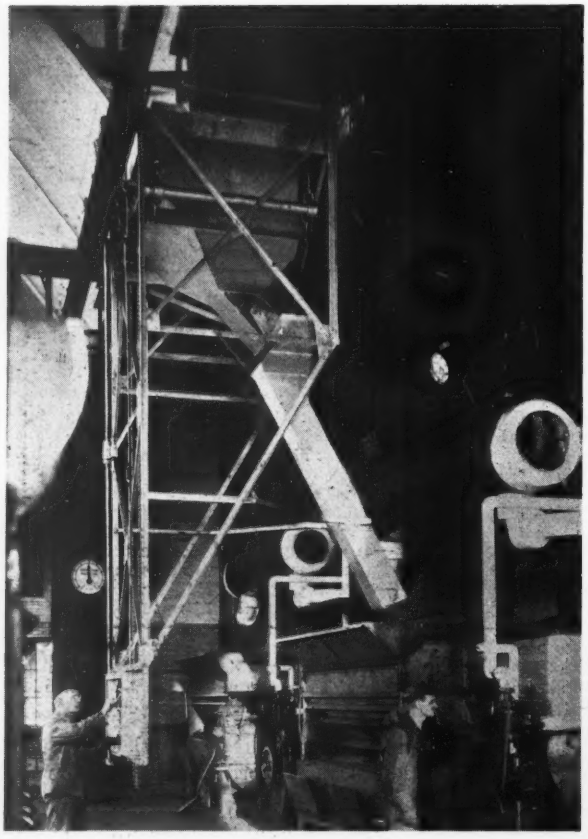
code. Supplementing these, but not replacing them, water level indicators and recorders are available for mounting on a control board.

Draft gages of the single differential type are not required for the safe operation of the boiler but have an economic value far outweighing their cost even in the smallest boiler plants, provided, of course, the fireman interprets the reading correctly and controls the combustion accordingly. No boiler should be without at least a three-point or double differential draft gage to give readings under the grate, in the furnace and in the breeching. More elaborate draft indicating and recording instruments are available and used extensively with large boilers, and are probably the greatest aid a fireman has in maintaining high boiler and furnace efficiency.

Feedwater and steam flow meters are of value in determining the cost of steam generation but are equally valuable in maintaining operating efficiency for they give a continuous indication of the load being carried thus furnishing information upon which the operator can distribute his load most effectively among the boilers in operation and adjust combustion conditions accordingly. The difference in readings between the total feedwater used and the total steam delivered is an indication of the water and steam lost in the steaming process due to such causes as blowing down boiler water and popping of the safety valve.

Common practice would indicate a steam flow meter of the indicating type to give the load on the entire plant. Except for extremely large boilers one feedwater meter for the entire plant appears to be good practice.

Combustion air may be measured or estimated in several ways, the most accurate being by means of an air flow meter. Correctness of combustion is indicated



Photo, Stephen-Adamson Mfg. Co.
Fig. 7. Weighing coal as it goes to individual boilers is the first step in economical steam production

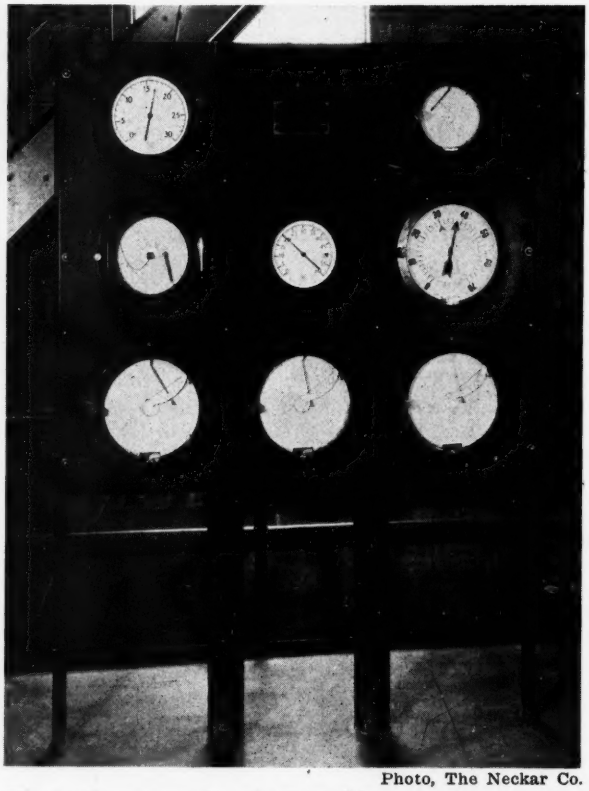
by gas analysis instruments, most important of which is the CO_2 machine which may be supplemented with a CO determination for more accurate indications. One or both of these instruments are used on large boilers with preference shown to the air flow meter, checked against flue gas analyses at various loads, as the air flow meter enables continuous comparison of steam flow and air flow which should be directly proportional and the recorded graphs should run parallel. In the small plant, the three-point draft gage may be used as a rough guide in proportioning combustion air to load on the boiler and this method should be used where more accurate means are not available.

The maintenance of temperatures within the narrow limits required for safe and economical operation of boilers demands extreme care, particularly in large boilers or those working at high pressures and temperatures. With working steam temperatures approaching the weakening point of the metal used in the construction, the safe operation of the boiler demands close attention, particularly to the temperature of the superheated steam which is an indication of the temperature of the superheater tubes although, of course, it does not give the temperature of any hot spots that may exist. Medium size boilers working at medium pressure and temperature are not subjected to so critical conditions, nevertheless, the instantaneous steam temperatures should be known to the attendant if possible and instruments for this purpose should be provided. With low pressure boilers, the steam temperature should always be indicated or recorded as a precaution against overheating the equipment supplied with steam.

A knowledge of feedwater temperatures is of value to the operator in maintaining efficiency of the steam generating unit under the existing load condition and also assuring proper operating conditions of the pumps, heaters and economizer. The recording type of thermometer is suggested here as a record is always valuable and its readings are visible to the attendant when desired.

Preheated air when used for combustion should have its temperature carefully controlled particularly when the boilers are stoker fired for expansion of the stoker parts due to high temperature may give operating difficulties. Thermometers here, are therefore essential, both from the standpoint of safety and efficiency.

In the operation of a boiler the greatest percentage of heat loss is usually that due to excess air supplied for combustion which comes to the plant at outside atmospheric temperature and leaves at stack temperature, the heat accumulated having been absorbed in some way from the fuel used in the plant, so reduction



Photo, The Neckar Co.
Fig. 8. Instruments for related conditions are most convenient when mounted together on panel

of stack temperature is a desirable objective. A flue gas thermometer may be used to indicate cleanliness of the boiler heating surface both inside and outside, also baffle conditions and infiltration of air into the boiler setting when its readings are compared with other instrument readings in the plant and properly interpreted. The recording type is the most desirable but in small plants an indicating thermometer can be used to great advantage.

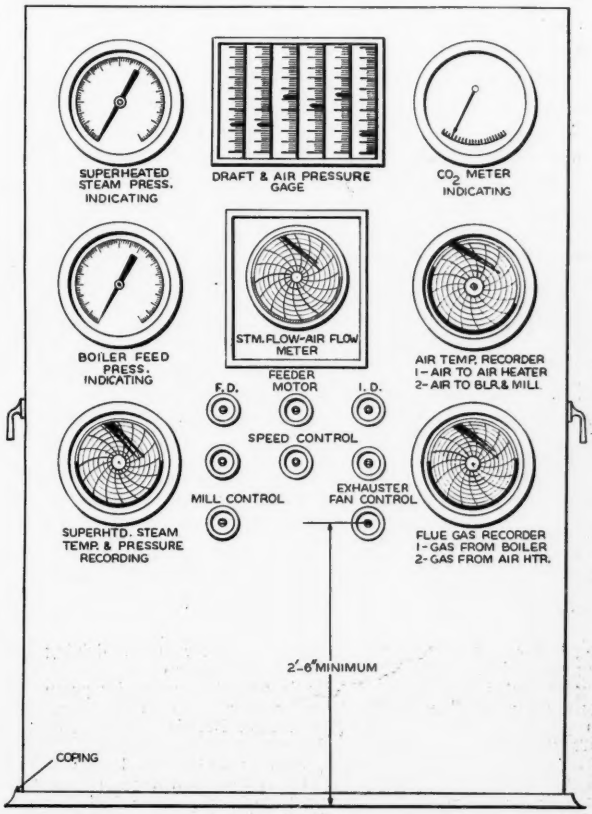


Fig. 9. Typical well designed boiler control panel

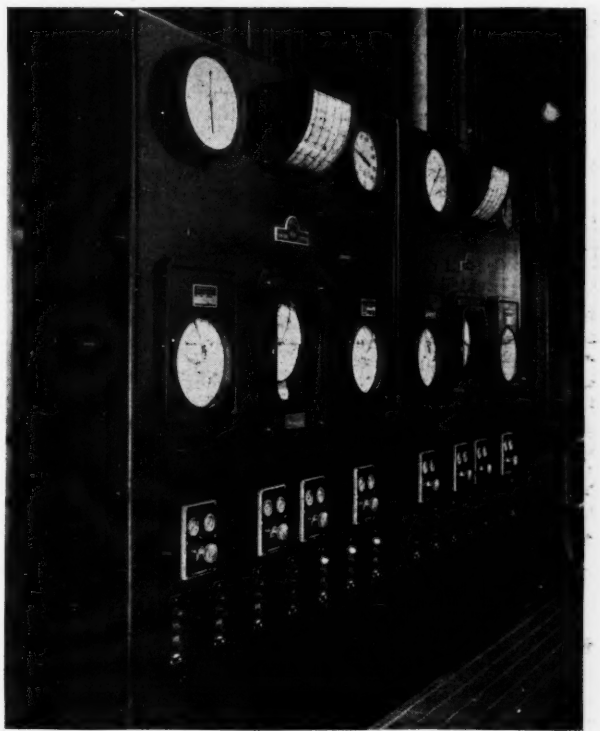
Some means should be provided in every fuel burning plant for registering the amount of fuel burned at least hourly, continuously if possible. A separate register for each large or medium size boiler is desirable, in small plants such complete provision may not be justified but it should have consideration as an aid in securing efficiency.

In the list of instruments suggested for steam generating units are blowoff water meters or thermometers, flue gas analysis instruments, smoke detectors and water analysis instruments all of which have been developed to meet the needs of power plant operators and are being used to advantage in many boiler rooms particularly where large boilers are in use. Their installation in almost every case is a question of possible savings to pay dividends on investment and upkeep.

Steam Turbine Generating Units

Pressure and temperature instruments are of first importance to the operator of a steam turbine and the instruments indicated in this table should give all the information which is necessary to keep the turbine in operation at its highest efficiency. For accounting purposes and to ascertain the unit efficiency, the input, indicated by the steam used, may be secured from a steam flow meter and the output from the watt-hour meter. All other instruments are used either to indicate the safety of operating conditions or to maintain the most efficient conditions. Turbine bearings demand constant watching and every aid possible should be given to the attendant in the way of instruments to indicate temperatures and pressures of oil and water used to serve the main bearings. Temperatures and pressures at bleed points are of particular value where the turbine bled steam is used in industrial processes.

Closely associated with the turbine is the condenser which serves it and all instruments commonly used in the operation of condensers are listed, some of these are duplicates of those used with the turbine and may be omitted for that reason. In calculating the overall



Photo, Bailey Meter Co.

Fig. 10. Control board for two boilers in industrial power plant

efficiency of the entire unit the power consumed by the pumps must be taken into consideration so these items should be totalized which can best be done by suitable totalizing instruments. Air meters to indicate the leakage into the exhaust steam space are not in common use but are being installed with large units. The same may be said of leakage indicators used to warn operators of the presence of impure circulating water in the condensate, a condition likely to give boiler water trouble.

The generator is the third main element of the unit and requires only a watt-hour meter to give information needed by the accounting department but the other instruments listed are of value to the attendants in maintaining proper operating conditions and effi-

ciency. Voltage and synchronism are requirements of the service rendered and must be maintained within very narrow limits. The load or wattage, which is a function of the voltage, amperage and power factor, is a variable over which the operator has little control except as it may be distributed among different generators. The instruments indicating these conditions should, therefore, be considered essential to operation. They include voltmeter, ammeters, wattmeter, power factor meter and tachometer or frequency meter. The synchroscope is a safety instrument used to throw switches at the proper instant when bringing an alternating current generator into service in parallel with other generators and is quite essential to satisfactory operation.

As reciprocating steam engines do not run at speeds comparable to turbines, the same degree of care in operation is not necessary, so the list of suggested instruments is considerably reduced. The load carried will be indicated by the generator wattmeter, if the engine drives a generator, or can be estimated from steam flow meter readings with sufficient accuracy for operating purposes. Steam pressures not given by other instruments conveniently located should be made known to the operator by means of instruments. Thermometers should be used to indicate the temperature of the exhaust steam particularly if used for heating or industrial purposes, and of main bearings of large engines subject to extreme pressure. Indication of the exact speed of an engine is not of great value to the operator except in special cases, as the engine governor is depended upon to maintain constant speed. A tachometer or frequency indicator on the driven a.c. generator may be used in case of necessity to indicate certain defects in the operation of the governor.

Instruments in the Delray No. 3 Plant of the Detroit Edison Co.

LOCATION OF INSTRUMENT PANEL BOARD OR INSTRUMENTS

In practically all cases, the instrument panel boards vital to the control of apparatus are close to the control points. The following instrument panel boards are installed in the plant at locations as described.

1. Turbine gage boards—One for each main turbine, located on the turbine room floor near throttle.
2. Central turbine room gage board—Located on turbine room floor.
3. Boiler feed pump gage boards—One for each main unit, located in condenser room adjacent to boiler feed pumps.
4. Heater gage boards—One for each main unit, and located in condenser room.
5. Miscellaneous isolated meters located at various points in turbine room and condenser room.
6. Boiler gage boards — One located on operating floor in front of each boiler.

INSTRUMENTS USED AND DESCRIPTION

The following instruments are located on each of the instrument panel boards.

1. Turbine Gage Boards
   - Indicating Pressure Gages
     - Main steam
     - Throttle
     - First stage
     - Overload
     - Vacuum
   - Mercury column vacuum gage
   - Recording pressure gage—oil to bearings
   - Recording thermometer — feedwater leaving high pressure heater
   - Recording tachometer
   - Wattmeter
   - Vibrating reed frequency meter
2. Central Turbine Room Gage Board
   - Panel for each d.c. unit and electrical control
   - Indicating pressure gages
     - Each main turbine throttle
     - Each d.c. turbine throttle
     - City water
     - Heating system header
     - Saturated steam header
     - General service water
     - Emergency service water
     - Main boiler feed
6. Boiler Gage Boards
   - Indicating pressure gages
     - Saturated steam
     - Superheated steam
     - Screen boiler
     - Main boiler feed
   - Indicating and recording steam flow meter
   - CO_2 and CO recorder
   - Indicating draft gage
     - Underfire
     - Overfire
     - Economizer inlet
     - Economizer outlet
     - Preheater outlet
   - Recording thermometers
     - Air entering preheater
     - Air leaving preheater
     - Gases leaving boiler
     - Gases leaving economizer
     - Gases leaving preheater
   - Recording pressure gage on flue blower lines
   - Recording draft gage
     - Underfire
     - Overfire
   - Miniature ammeters for fan motors and stoker motors
   - In boiler aisle
     - Pilot pressure gage
     - Load indicator
     - Clock
     - Auxiliary boiler feed
     - Station steam
     - Sealing water
     - House service air
   - Recording pressure gages
     - Main boiler feed
     - Auxiliary boiler feed
     - Station steam
   - Thermocouple pyrometer and selector switch for indicating temperature of steam to each turbine
   - Recording flow meters for discharge from each boiler feed pump
   - Storage water level indicator
   - Storage water level recorder
   - Mercury barometer
   - Annunciator panel with signal lights
     - Low oil, main units
     - High temperature, generator air
     - Low oil, d.c. units
     - Low water, intake canal
     - Low water, storage tanks
     - Excessive transformer temperture
     - Low water pressure on transformer
     - D.c. machine circuit breakers
     - 4800 volt bus (auxiliary)
   - On Turbine Room Wall:
     - Load indicator
     - Clock
     - Signal lights to indicate for each main turbine and d.c. turbine:
       - Next machine on
       - Machine running
       - Next machine down
3. Boiler Feed Pump Gage Board
   - Indicating pressure gages
     - Main boiler feed
     - Auxiliary boiler feed
   - Steam gages for turbine driving emergency pump
   - Indicating flow meter for pump discharge
4. Heater Gage Boards
   - Indicating pressure gages
     - Steam entering each heater
     - Steam in evaporator coil
     - Steam in evaporator shell
   - Duplex index thermometers for steam entering and water leaving each of the heaters
   - Recording thermometers for air entering and leaving generator air cooler
5. Miscellaneous Isolated Meters
   - Pedestal mounted steam flow meter of the recording, integrating type for each main unit
   - Pedestal mounted steam flow meter of the recording, integrating type for each d.c. house service turbine
   - Duplex index thermometer for temperature of water entering and leaving condenser for each main unit, located near controls for variable speed motors on circulating pumps for each main unit
   - On condenser room wall
     - Signal lights to indicate for each main turbine and d.c. turbine:
       - Next machine on
       - Machine running
       - Next machine down
   - Venturi meter of the indicating, recording, integrating type in the boiler feed riser from each main unit

Suggested Diesel Engine Instruments

Instruments required to supply the accounting department with information necessary to determine the economic value of the Diesel engine generating unit consist of a watt-hour meter to register the output of the unit, a fuel oil meter and means for recording the amount of lubricant used. For operation purposes, the governor will maintain the speed with sufficient accuracy but a tachometer or frequency meter may be advisable under exacting conditions. The pressure and temperature instruments listed are valuable to the attendant in his task of keeping the engine in the best of condition and as free as possible from repair costs, as well as high in thermal efficiency.

Hydraulic turbines driving electric generators will have their load indicated by the wattmeter on the generator while the governor will maintain constant speed within limits, variations in voltage may indicate the necessity of a tachometer frequency meter to study the causes of and remedy for speed variations. Head water pressure and tail water level should be made a matter of record as they both vary with weather conditions and govern plant output as well as the program of operation to a large degree. A record of the water temperature is also of vital importance particularly during extremely cold weather when ice troubles are imminent. Bearing troubles are usually first indicated by a rise in temperature during operation and indicating thermometers on the main bearings may save expensive repair so should be considered for all sizes of units.

Auxiliary Equipment

Instruments considered for installation on the principal auxiliary equipment have their value in indicating how nearly the purpose of this equipment is being met. Here again safety must have first consideration but as a rule auxiliary equipment is installed because of its ability to improve the overall economy of the plant and without sufficient instruments to keep the operators informed on conditions affecting economy will, to a great extent, destroy the purpose of the equipment. With this thought in mind the lists of instruments for such equipment as feedwater heaters, pumps, fans, motors driving all types of auxiliaries have been prepared and suggested here as representing practice in the most efficient modern plants.

In addition to the instruments already listed, consideration and study should be given to the instruments which will guide the operators in keeping the service apparatus in the best of operating conditions and ready at all times to serve the main units. The following list of equipment and data helpful to the attendant in regular operation may suggest means by which the information may be imparted by instruments otherwise provided in the plant or those which may be considered necessary for safe and economical operation.

Piping—Pressure, temperature, velocity of contained liquid, expansion, radiation, condensation.

Stokers—Fuel handled, power consumed, speed.

Pulverizers—Fuel handled, power consumed, velocity, air temperature, air velocity.

Coal and ash handling equipment—Quantities handled, power consumed.

Feedwater treatment system—Quantities of chemicals used, analyses of raw and treated water, amount of water treated, back wash water used, pressure drop through filter.

Transformers—Power converted, voltages and currents of primary and secondary circuits, temperatures of coils, oil and cooling water or air.

Converters—Volts, current and watts of both elements, bearing temperature.

Storage battery—Voltage, charge and discharge current, temperature of pilot cell, density of electrolyte.

Crane—Power used.

Condensing water screen—Power used, water level on both sides.

Evaporators—Temperatures of steam supply and condensate, water inlet and vapor, steam pressure, water pressure, amount of steam used, amount of water evaporated.

Cooling pond or tower—Air temperature and humidity, temperature of water to and from, water level in reservoir, power for pumps and fans.

Coal storage pile—Temperature below surface that is liable to cause spontaneous combustion.

The same approach as has been described may be taken to what other units may be installed in the plant and when their locations in the plant have definitely been settled the task of determining the location of control boards and their instruments is next in order. With this problem is included that of eliminating duplicated instruments where such is possible without impairing safety. One of the principal features of control board design is to arrange the indicating instruments so that the effects of adjustments being made are plainly visible to the operator while he is working the control mechanism. Several conventional arrangements of boiler control panels are shown.

In small plants a control board in the boiler room and another in the engine or turbine room will usually be found sufficient with the addition of single panel pedestals for special or remote equipment. As the plant increases in size the number of control or instrument panel boards is increased, as may be noted by the instrument equipment listed here of the Delray No. 3 plant of the Detroit Edison Co., which is one of the most completely equipped plants in the country and also one of the most efficiently operated.

No satisfactory method has yet been devised for determining within reasonable limits what the economic value of a particular instrument may be, as so much depends upon the character of the operating force. Instruments installed for the purpose of increasing efficiency of operation must pay for their investment and upkeep costs out of savings accomplished. Units or plants that cost little to operate do not offer much opportunity to save a great amount of money. It is only as this expense runs up due to the size and inefficiency of the equipment that the percentage of possible savings mounts to attractive figures. These may be determined to some extent by running efficiency tests under operating conditions and if the unit is running at low efficiency because of the lack of proper instruments, estimates can be made as to what this lack of instruments is costing and how much investment in instruments is justified.

Instruments *for* Testing Power Plant Equipment

Photo, Hays Corp.

What to expect from installed equipment is best established by carefully controlled tests aided by instruments calibrated for accuracy

TESTS conducted in power plants may be classified under three general headings, depending upon the purpose for which the test is desired. These are acceptance tests, performance tests and research tests. While each class of test may be done most conveniently with specific types of instruments, from the standpoint of economy operating instruments should be used as far as it is possible to do so.

Acceptance tests are frequently highly controversial as they are conducted to determine whether or not the equipment under test will meet the guarantees made by the manufacturer. When of considerable importance, they should be supervised by a competent, unbiased engineer not regularly employed by either the manufacturer or purchaser. In such cases all instruments used in securing data are either furnished by the test engineer or calibrated under his supervision as accuracy is of extreme importance. It is customary for both parties to the test to have representatives present to observe the conduct of the test. In some cases, however, preliminary tests are run by the power plant testing force, in which case the instruments are, of course, provided by the plant but as a rule the same degree of accuracy is not required here, and operating instruments, carefully calibrated, will suffice where they are available. Portable instruments, however, are necessary in order to secure data not made available by the operating instruments. The accompanying tabulations give the data required and the instruments and apparatus necessary to conduct the usual acceptance tests of the principal equipment in power plants as recommended by the Power Test Codes of the A.S.M.E. Checking these lists against the operating instruments will give the equipment which must be provided from the plant laboratory or from some outside source.

Performance tests are conducted for an entirely different purpose and are within the duties of the operating or testing force, if such is maintained. These tests usually have several objectives, such as efficiency after a period of operation, efficiency at different loads, endurance under unusual load conditions, response to varying loads, suitability of various types of fuels, lubricating oils, water treatment and any other operating problem which is up for solution. For these tests, the operating instruments that are installed are usually checked for accuracy, and what additional instruments are necessary, usually of the portable and more accurate type, are taken from the plant laboratory or secured from some outside source. The list of instruments required depends upon the object of the test but as a rule can be made up from the lists given in the test codes. In many respects the usual type of recording and totalizing operating instruments are far more convenient than the indicating type commonly used in formal tests as they reduce the number of men necessary to conduct a test. The principal objection to their use is the accuracy of their readings but this is rapidly being overcome by improvements incorporated in instruments of modern design.

Research tests are rarely conducted by the operating staff of a power plant but some large companies do maintain research departments that call in the assistance of test and operating engineers to secure data when conducting tests requiring field information. Research testing as a rule is scientific work re-

quiring specialized technicians to conduct it and quite out of the field of power plant work, so that necessary instruments, other than those required for other purposes about the plant would scarcely be considered as part of the plant equipment and will not be considered here.

In this discussion of instruments used for testing purposes it is the intention to deal only with those that must be specially provided, that is, those that are not usually permanently installed as part of the operating equipment having discussed appropriate instruments for operating purposes in the previous article and assuming that this equipment can be calibrated and made sufficiently accurate for the tests to be made.

With these lists of instruments in hand a classification of those required for the class of testing which the plant force will be called upon to do can be made similar to that published in Gebhardt's book, Steam Power Plant Engineering, which is reprinted here with some additions to bring the list up to date. Checking this list against those permanently installed in the plant, which are available for the tests to be made, and eliminating those not required will indicate the instruments which the plant testing department should have supplied for its laboratory. Some comment on the suitability of different types of equipment, however, may be helpful.

In all tests considerable stress is laid upon the accuracy of the data secured. Much of this depends upon the design of the instrument or equipment used in collecting the information, so commonly accepted instruments or those recommended by test codes should be used or, by all means, used in calibrating the instruments employed in collecting data.

Weights

Because of their simplicity and ease with which they can be checked for accuracy, platform scales have become classical equipment for test purposes. A convient size for moving around to suitable locations can weigh up to 1000 lb. which would be sufficiently large for nearly all power plant purposes. They are used in many cases for weighing fuel, ashes and water and, although the common type is manually adjusted and weights recorded, more convenient equipment which automatically indicates and graphically records the weights as the loads pass over the platform are available. To reduce the amount of work, the weight recording equipment used in regular operation should be used where possible for testing after it has been calibrated.

While many engineers still consider that scales are the only weighing equipment sufficiently accurate for testing purposes, great advancement has been made in the accuracy of meters and when checked they can be used for measuring water with readings sufficiently accurate for performance purposes. Where large quantities of water are involved some form of weir makes a convenient device and for testing hydraulic turbines of large capacity several other methods have been devised, such as pitot-tube, pressure-time, salt-velocity, venturi-meter and current-meter, all of which have been used and have a recognized standing among engineers.

Weighing steam as such, is of course, impossible, so either the water before it is made into steam or the condensate after the steam has served its purpose must be weighed if direct weight is required. A more convenient method, is the use of steam meters of the totalizing types. The various types of fluid meters as

Testing and Measuring Apparatus for Steam Plant

Weights		
Fuel	Platform scales, indicating and recording	
	Suspension hoppers, indicating and recording	
	Coal meters, totalizing	
Fluid	Platform scales and tanks	
	Volumetric	Indicating, recording and totalizing
	Current	
	Area	
	Dynamic	
	Weir	
	Force	
	Thermal	
Pressures		
High	Bourdon gage, indicating and recording	
	Manometers, mercurial, indicating	
Low	Manometers—mercurial, indicating and recording	
	Manometers—water, indicating and recording	
	Diaphragms, indicating and recording	
Temperatures		
−300 to +1300°F.	Electric resistance thermometer	
−40 to +800°F.	Mercurial glass thermometers	
−60 to +200°F.	Liquid pressure thermometers	
+50 to +400°F.	Volatile-liquid pressure thermometers	
+120 to +1000°F.	Gas pressure thermometers	
0 to +1600°F.	Base metal thermocouples.	
+800 to +2900°F.	Rare metal thermocouples	
Over 2900°F.	Optical and radiation pyrometers	
Power		
Indicated	Indicators, hand-manipulated	
	Indicators, continuous recording	
Developed	Rope brake	
	Prony brake	
	Absorption dynamometers	
	Electric generator	
Flue-gas Analysis		
Orsat apparatus		
Hand analyzers		
Recorders		
Electrical		
Speed		
Tachometer, indicating and recording		
Revolution counter, totalizing		
Frequency meter, indicating and recording		
Stroboscope, indicating		
Moisture		
In air	Hygrometer, indicating and recording	
In steam	Calorimeters	Separating, Throttling
Fuel Heat Value Analysis		
Coal calorimeters		
Gas calorimeter		
Uses for Chemical Instruments in Power Plants		
Fuel analysis	Proximate and ultimate	
Oil analysis	Viscosity, flash point, acidity	
Water analysis	Scale forming impurities, soluble salts, acidity, dissolved oxygen	
Electrical Plant		
Voltage	Voltmeters, a.c. and d.c., indicating and recording	
Current	Ammeters, a.c. and d.c., indicating and recording	
Output	Wattmeters, a.c. and d.c., totalizing and recording	
Power factor	Power factor meters, a.c. only, indicating and recording	
Frequency	Frequency meter, a.c. only, indicating	
Synchronism	Synchronizers, a.c. only, indicating	
Wave form	Oscillograph, indicating and recording	

indicated in the list given here and their principles of operation are described in another article of this issue but a few words on the different types as related to testing may not be amiss.

Instruments used in the regular operation of equipment are permanently installed and are chosen because of their simplicity, their rugged construction that insures long life under continuous service, their minimum demands for attention and freedom from interference with the continued operation of the equipment it serves and, while accuracy of readings is highly important in securing operating data, the comparative readings from hour to hour and day to day as taken from the same meter are of more value to the operator than extreme accuracy. When tests are conducted, however, more exact determinations are usually required as the comparisons to be made are usually with other equipment and other meters or theoretical results. Permanently installed meters should, therefore, be calibrated before starting a test. Much of the testing requiring fluid measurements, however, is done on equipment that is not provided with operating meters that give the desired measurements. This makes necessary the provision of suitable testing meters.

As previously stated, positive weighing is to be preferred where important and controversial tests are concerned. Then there is that division of meters designated as positive which may be either of the weighing or volumetric class. Weighers and tilting traps are types of the weighing class, while in the volumetric class are such types as tank, piston, disk, rotary, bellows and wet drum. These weighing or measuring elements of the meter actuate counters as each successive weight or volume of the fluid passes through the meter and thus produces the desired record. Another division, designated as inferential, do not pass the fluid through in separated increments but in a continuous stream so that positive operation of the counting mechanism is not required for determining the rate of flow of the fluid. The quantity passed is inferred by the position of the indicating mechanism and recorded or totalized by means of clock work mechanism.

Quantity meters that come under this division are classed as current meters and include such types as propeller, anemometer, turbine and helical. Rate of flow meters come under the inferential division, the head class including venturi, flow nozzle, thin-plate orifice, pitot, centrifugal and friction. The area class takes in gate, orifice and plug, cone and disk, and cylinder and piston types; the head-area class includes such types as rectangular notch, triangular notch and

Stationary Steam-Generating Units

MEASUREMENTS

(a) Area of heating surfaces.
(b) Grate surface.
(c) Furnace volume and dimensions.
(d) Analysis and heating value of fuel.
(e) Steam pressure.
(f) Quality of steam.
(g) Analysis of gases.
(h) Draft pressures at various points.
(i) Steam temperatures.
(j) Superheat.
(k) Various air temperatures.
(l) Gas temperatures.
(m) Feedwater temperatures.
(n) Weight of fuel.
(o) Weight of refuse.
(p) Analysis of refuse.
(q) Weight of water.

INSTRUMENTS AND APPARATUS

(a) Scales for weighing coal, oil, or other fuel, ashes, furnace refuse, etc.
(b) Graduated scales for water level measurements.
(c) Tanks or tanks and scales for volumetric or weight measurement of water.
(d) Meters or other apparatus for measuring gaseous fuels.
(e) Pressure and draft gages.
(f) Thermometers and pyrometers.
(g) Calorimeter for determining the quality of the steam.
(h) Gas-sampling and analyzing apparatus.

Feedwater Heaters

OBJECT

(a) To determine whether the heater meets the designed conditions.
(b) To determine the variation of temperature rise of water and friction drop in water with capacity in the case of closed heaters.
(c) To determine the closeness with which the outlet-water temperature approaches the steam temperature corresponding to the pressure in the open heater.

INSTRUMENTS AND APPARATUS

(a) Barometer, preferably of the mercurial type.
(b) Mercury columns for measuring vacuum and low pressures having scale graduations of not greater than 0.1 inch with vernier attachment.
(c) Bourdon gages for measuring pressures when too high for mercury columns.
(d) Thermometers:
  (1) For determining temperatures of feedwater, condensate and vapors—graduated by half degrees and with scale readings from 32 to 300 or 350 deg. F.
  (2) For determining steam temperature, graduated in degrees with scale readings from 32 to 300 or 350 deg. F.
(e) Tanks and platform scales for measuring water (or water meters calibrated in place under conditions of use).
(f) Steam calorimeter, throttling or separating, depending upon amount of moisture present and pressure.
(g) Apparatus for testing oxygen content of water.

Steam Turbines

MEASUREMENTS

(a) Load.
(b) Steam used.
(c) Condenser leakage.
(d) Steam conditions at throttle and exhaust.
(e) Speed.
(f) Time.

INSTRUMENTS

For a turbine running alone, a dynamometer of a type suitable to the turbine and the circumstances of the test.

For a turbine-generator, instruments for the measurement of generator output.

For a turbine exhausting to a surface condenser, water-weighing tanks and scales, or properly constructed volumetric measuring tanks, and suitable instruments for the measurement of condenser leakage.

For a turbine exhausting to atmosphere or to a jet condenser, water-weighing or measuring tanks and a boiler suitably isolated, or facilities for calibrating the first-stage nozzle block.

A Bourdon or deadweight gage for measuring steam pressure on the boiler side of the throttle valve and strainer.

If saturated steam is used, suitable instruments for determining its quality on the boiler side of the throttle valve and strainer.

If superheated steam is used, proper thermometer and well for determining its temperature on the boiler side of the throttle valve and strainer.

Mercury columns, deadweight gages, or accurate Bourdon gages, for determining vacuum or pressure of the exhaust steam.

Mercury barometer.

Thermometers for determining temperature of mercury columns and barometer.

Speed indicator.

Clock, or synchronized watches.

special notch; in the force class are hydrometric pendulum and vane types; and in the thermal class is the electric type.

While lacking somewhat in accuracy most of the inferential types of fluid meter have the decided advantage, for occasional testing of equipment, that they are comparatively easy to install, and inexpensive indicating types suitable for test purposes can be selected as part of the test equipment of the plant.

Pressure Measuring Instruments

Accuracy of pressure measurements is of prime importance when conducting tests on power plant equipment as many services rendered by a plant depend upon the maintenance of pressures within very narrow limits. Fortunately the common pressure instruments that are available for test purposes, as well as operation, maintain a high degree of accuracy, are simple in construction, easy to install and, compared

Reciprocating Steam Engines

Measurements

(a) Cylinder diameters and stroke.
(b) Diameters of piston rods and tail rods.
(c) Indicated horsepower.
(d) Brake horsepower or shaft horsepower output.
(e) Kilowatt output if engine is connected to a generator.
(f) Speed in revolutions per minute.
(g) Pressure in the steam pipe before the throttle.
(h) Barometric pressure.
(i) Percentage of moisture or number of degrees of superheat in the steam just before the throttle.
(j) Back pressure in the exhaust pipe near the engine cylinder.
(k) Pressures in receivers.
(l) Weight of return drips from jackets, reheaters and receivers.
(m) Weight of the condensed steam in pounds or the weight of the water fed to boilers, less drips and leakage, if the test is based on feedwater measurement.

Where additional information is desired the following items should be considered:

(n) Volumetric clearance in per cent of the piston displacement.
(o) Temperature of the exhaust steam leaving all cylinders.
(p) Temperature of the drips, if any, from jackets, reheaters and receivers.
(q) Temperature of steam leaving receivers, cylinder jackets, reheaters and similar parts.
(r) Any unusual conditions should be noted.
(s) Engine room temperature and outside air temperature.
(t) Variation in steam pressure in the steam chest.

Instruments and Apparatus

(a) Tanks and platform scales for weighing water (or water meters calibrated in place).
(b) Graduated scales attached to the water glasses of the boilers if the feedwater is measured.
(c) Pressure gages, vacuum gages or mercury columns and thermometers provided with suitable mercury wells.
(d) Steam calorimeters and extra calibrated thermometers.
(e) Barometer.
(f) Steam-engine indicators.
(g) Planimeter.
(h) Tachometer, revolution counter, or other speed-measuring apparatus.
(i) Friction brake or other type of dynamometer.
(j) Appropriate electrical instruments if engine is connected to an electric generator.

Internal-Combustion Engines

Measurements

(a) Bore and stroke and clearance of power cylinders.
(b) Diameters of piston rods and tail rods of power cylinders of double-acting engines.
(c) The brake-horsepower or shaft-horsepower output.
(d) The kilowatt output of engine if direct-connected to a generator.
(e) The speed in revolutions per minute.
(f) The horsepower to drive the independent cooling-water pump and fuel-pump (if any).
(g) The horsepower to drive the independent scavenging pump or blower.
(h) The horsepower to drive the independent injection air compressor.
(i) The amount of fuel supplied: cubic feet of gas for gas-burning engines, or pounds of liquid fuel for liquid-fuel engines. If more than one kind at the same time, the amount of each kind.
(j) The calorific value of the fuel, high value.

Instruments and Apparatus

(a) Scales with or without special auxiliary apparatus for weighing liquid fuel, with or without tanks to be used in coöperation.
(b) Gas meters for measuring gaseous fuel, or gas-metering methods with indirect observation apparatus.
(c) Gas calorimeters for determining the heating value of gaseous fuels.
(d) Beaumé oil hydrometer for petroleum liquid fuel, and for indirect determination of calorific power.
(e) Pressure gages and mercury or water columns for measuring small pressures and vacuums.
(f) Thermometers.
(g) Barometers.
(h) Gas-engine and oil-engine indicators for working cylinders and steam-engine indicators or special low-scale springs for cylinders of two-cycle scavenging pumps and low-pressure cylinders in injection air compressors.
(i) Pressure-indicating or recording instruments for compression pressures or injection pressures in cylinders.
(j) Planimeters.
(k) Tachometers, revolution counters or other apparatus for measuring speed or number of fuel admissions per minute.
(l) Absorption dynamometers of appropriate type for the horsepower, speed and torque of the engine to be tested, especially hydraulic brakes and electric dynamometers.
(m) Appropriate electrical instruments and apparatus, if the engine is direct connected to a generator, to provide a suitable electrical load and to measure it.

Steam Condenser

Principal Data and Results

Dimensions of condenser and auxiliaries.
Data regarding prime mover or other apparatus exhausting to condenser.
Data regarding types and special features of all auxiliaries.
Steam condenser per hour.
Auxiliaries:
  (a) Steam or power consumed by auxiliaries.
  (b) Per cent of (a) to total steam or power of apparatus exhausting to condenser.
Absolute pressure at condenser exhaust nozzle.
Temperature of condensate in well.
Difference between temperature of steam entering condenser and temperature of water in hot well.
Circulating water:
  (a) Quantity.
  (b) Temperature at inlet.
  (c) Temperature at outlet.
Heat transfer per degree difference of temperature per sq. ft. of condensing surface per hour:
  (a) Arithmetical.
  (b) Logarithmic.
Volume of air removed per minute at 60 deg. F. and 14.7 lb. abs.

Instruments and Apparatus

(a) Barometer, of the mercurial type.
(b) Mercury columns for measuring vacuums having the smallest scale graduations not greater than 0.1 in. and with vernier attachment permitting readings accurate to 0.01 in.
(c) Bourdon gages for measuring pressures when too great for mercury manometer tubes.
(d) Thermometers:
  (1) For determining temperatures of circulating water, condensate and vapors—graduated by half-degrees and with maximum scale readings from 32 to 150 deg. F.
  (2) For determining steam temperature graduated by degrees and with maximum scale readings from 32 to 250 deg. F.
(e) Tanks and platform scales for measuring water (or water meters calibrated in place under conditions of use).
(f) Appliances for tests of auxiliary pumps such as steam-engine indicators, electrical instruments, speed indicators, etc.
(g) Air-measuring devices—gasometer or calibrated orifices.

to instruments for most other purposes, inexpensive in first cost. As indicated in the list, Bourdon gages and mercurial manometers are suitable instruments for high pressure indications while for low pressures either mercurial or water manometers or diaphragm gages will be found suitable equipment for the testing department, with the addition of a dead weight gage for calibrating purposes.

Thermometers

Many tests conducted in power plants require the recording of temperatures within narrow permissible margins of error and thermometers must be chosen carefully for the specific purposes for which they are intended to be used. Points to be considered are: the range of temperatures to be observed, the length of scale divisions, the accessibility of the point where temperatures are to be determined, the liability of injury to the thermometer and legibility of scale.

Without question the most common and one of the most accurate types is the mercurial glass thermometer with the scale etched on the glass tube. Such thermometers are made for temperature readings from —40 to +800 deg. F. which covers nearly the entire range of temperatures existing in power plants except in furnaces and unusually high temperature steam. Mercurial glass thermometers, however, are fragile and for this reason cannot be used universally. The other types listed should be considered as special and used only where the mercurial type is out of the question. Electric resistance thermometers and thermocouples have a distinct field covering a wide range of temperatures in spots that are difficult to reach in any other way. They can be used to advantage in exploring for temperature conditions or as permanent elements in boiler settings. Another application is in the windings of electrical machinery such as generators, motors and transformers, or when investigating radiation through thick metals, boiler walls or insulating materials. Liquid and gas pressure thermometers are convenient types for remote readings and recording indications, and are commonly used for operating purposes. Optical and radiation pyrometers occupy the field above 2900 deg. F. and are helpful in studying furnace conditions.

No power plant using reciprocating power ma-

Refrigerating Systems

Measurements

(a) The quantity of the refrigerant circulated.
(b) The various temperatures of the refrigerant in the cycle.
(c) The various pressures of the refrigerant in the cycle.
(d) The energy required to operate the driving element and the various auxiliary apparatus.
(e) The various temperatures of condensing and cooling water.
(f) The quantity of condensing and cooling water.
(g) Quantity, quality and pressure of steam used in the steam cylinder or generator.
(h) Principal dimensions of driving element.
(i) Quantity of composition and density of brine used.
(j) Temperature of brine entering and leaving the evaporator.
(k) Quality of liquor used in absorption plants.

Instruments and Apparatus

(a) Suitable meter for measuring liquid refrigerant on the high or intermediate-pressure side where it passes to the expansion coils of the brine cooler or elsewhere.
(b) Platform scales and suitable tanks for measuring water and condenser steam.
(c) Water meters, calibrated tanks or tank and platform scale for measuring condensing and cooling water.
(d) Pressure gages and vacuum manometers including a suitable U tube or mercury column to be connected at the low pressure suction of the compressor. It is recommended that this be used in all cases rather than a pressure or vacuum gage for suction pressures under 20 lb. gage.
(e) Calibrated thermometers and thermometer mercury wells of sufficient length to extend beyond the centers of the pipes. Thermometers used for taking temperatures of brine shall be graduated in 1/10 deg. F. and readings estimated to 1/100 deg. F.
(f) Barometer and psychrometer.
(g) Revolution counter or other accurate speed measuring device.
(h) Graduated stroke indicator for direct-acting pumps.
(i) Pycnometer, Mohr-Westphal balance, or calibrated hydrometer for specific gravity of brine.
(j) Calorimeter for determining the quality of the steam.
(k) Steam and ammonia indicator.
(l) Planimeter.
(m) Appropriate instruments for measuring power consumption of motor-driven machines.

Displacement Compressnrs and Blowers

Measurements

(a) The quantity of air or gas compressed and delivered expressed in cubic feet in terms of gas or air under intake conditions of temperature and pressure.
(b) The average instake and discharge pressures.
(c) The power required to compress and deliver the measured amount of air or gas handled.
(d) The amount of steam, electrical energy or fuel, depending upon the method of drive, consumed by the driving element during the test.
(e) Diameter and stroke of compressor cylinders, or equivalent dimensions for positive rotary blower.
(f) Diameter of piston rods.
(g) Number and dimensions of intercoolers and after-coolers.
(h) Principal dimensions of driving element.
(i) Speed in r.p.m. and total number of revolutions.
(j) Indicated horsepower in compressor and driving cylinders.
(k) Discharge pressure.
(l) Intake pressure.
(m) Intercooler pressure.
(n) Barometric pressure.
(o) Temperature of air or gas before and after each stage.
(p) Temperature of cooling water at inlet and outlet of each jacket and cooler.
(q) Quantity of jacket and cooling water.
(r) Temperatures, pressures, etc., steam, gas or oil as applied to driving element.

Instruments

(a) Gaging tank and nozzle or orifice for measuring air or gas compressed.
(b) Tanks and platform scales of suitable capacity for measuring the quantity of condensed steam when a steam engine constitutes the driving element or for measuring fuel oil when an oil engine constitutes the driving element.
(c) Water meters or calibrated tanks, or tanks and platform scales for measuring jacket and intercooler circulating water.
(d) Pressure gages, vacuum gages, water and mercury manometers, and thermometers.
(e) Barometer.
(f) Steam calorimeter (for steam-engine-driven compressor).
(g) Voltmeter, ammeter, wattmeter and power-factor meter for measuring electrical input and motor-driven compressors.
(h) Revolution counter.
(i) Indicators.
(j) A planimeter.
(k) A deadweight gage tester.
(l) A watch or other suitable timepiece.

chinery would be adequately equipped without an engine indicator with a set of springs suitable for the equipment in the plant. With this instrument not only can the indicated horsepower of any reciprocating engine be calculated but the entire pressure cycle is pictured and can be studied for defects and improvements, it is the greatest aid, in the form of an instrument, which is available to engineers in improving efficiency of steam and internal combustion engines. While the hand-manipulated type is the commonly used instrument, the continuous recording indicator is valuable in making test runs with varying loads.

Occasions sometimes arise in power plants when it is deemed advisable to determine the power developed characteristic of the driving element. Rope brakes and prony brakes are two of the most common types of the whole class of absorption dynamometers, which together with electric generators make up the list of power measuring equipment that may be used in these tests, depending upon the size of the unit and the nature of the driven load. Rope and prony brakes are applicable to equipment of less than 250 hp. where the speed does not exceed 1000 r.p.m. For higher capacities and higher speeds some form of electric generating device is usually employed. For plant testing equipment, however, one of the simple forms of absorption dynamometers will usually be found sufficient.

Speed Determinations

Many service conditions in a plant require speed regulation of the equipment within narrow limits and when testing this equipment some such device as a tachometer is most helpful for it gives continuous indication or record, if of the recording type, permitting a study of the causes of variations in speed such as defective governor action, varying load, varying voltage, power factor disturbances, irregular steam pressure. The revolution counter is a totalizing device which may be of the hand type, suitable for checking purposes and used in determining power output of engines, or of a type that automatically adds revolutions or strokes which are of value in pump tests, the lack of an accurate timing element discounts its value in hunting governor troubles.

In alternating current test work the frequency meter may take the place of the tachometer. The frequency of an alternating current circuit is the product of the speed and the number of pairs of poles on the field of the generator. As an indicator of speed, the scale is graduated in speed instead of frequency.

Among the newer types of speed measuring instruments is the stroboscope which is a device for comparing the speed of the equipment under test with that of a controlled-speed, pulsating-light source, when the machine under test gives the optical illusion of being at rest the speed of the stroboscope is the same as that of the machine. This device can be used successfully in determining the speed of light powered machinery where the load to drive another type of a speed-measuring instrument would materially reduce the speed.

No better method has yet been devised for determining the correctness of combustion than a chemical analysis of the products of combustion so gas analysis instruments are essential to the test equipment of a power plant. The most complete convenient test instrument is a portable Orsat set which will test gases for CO_2, CO and O_2. Although the boilers may be equipped with recording CO_2 machines used in regular operation, the Orsat testing set should be used to check the calibration of the recording machines and to explore the gas passages for combustion conditions.

Hand analyzers that determine only CO_2 have been found of aid in small plants because of their simplicity of operation and electrical devices that indicate CO_2 percentages are more suitable as operating aids than for testing purposes.

For determining moisture in air the hygrometer is probably most convenient, the use, however, of wet and dry bulb thermometers with the aid of a psychrometric chart is customary in many plants.

Two types of calorimeters are used extensively in determining the quality of steam and should be included as part of the testing equipment. The separating type is applicable to steam that has a high percentage of moisture, say more than 5 per cent, and works on the principle of throwing the moisture out of the steam by centrifugal force. The throttling calorimeter determines the moisture present by the temperature of the steam after passing through an orifice, the throttling effect being used to evaporate the moisture. Moisture determination is an important part of testing nearly all steam using equipment and calorimeters are quite essential.

Heat of Fuel

Determinations of the heat value of fuels are accomplished by means of coal or gas calorimeters that are laboratory instruments and are considered necessary only for power plants of the largest sizes and then only when the fuel shipments vary considerably in quality. Considerable skill is required to make these analyses and most plants depend upon an outside laboratory for heat value determinations.

A number of chemical analyses, however, are quite essential to the efficient operation of a power plant and can be conducted by a trained test engineer with chemical laboratory equipment that will have sufficient use in a medium and large size plant to warrant the investment. These tests are the proximate analysis of fuels, tests of lubricating oils and greases and chemical tests of water before and after treatment, in the boiler and condensate returns.

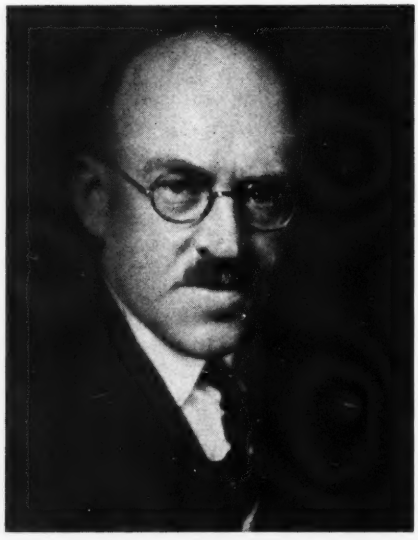
Electrical instruments used for test purposes are, as far as possible, those installed as aids in operation which have been calibrated for the purpose. A full complement of electrical instruments is listed here, each will perform a specific service in the most satisfactory way but for the small plant nearly all necessary electrical testing can be done with portable voltmeters, ammeters and wattmeters.

Power plant testing in nearly all cases has for its purpose the setting up of standards for the operating staff to follow in the handling of equipment and to accomplish this purpose, the testing department should be adequately equipped with instruments of the portable type and apparatus that can be moved from one unit to another without difficulty.

A. S. M. E. Holds Fifty-fifth Annual Meeting

Brighter Business Outlook Encourages Engineering Progress. C. E. Davies Made Secretary. Many Papers Presented on Problems of Operation

FROM MONDAY, December 3, to Friday, December 7, those in attendance at the Fifty-fifth Annual Meeting of the American Society of Mechanical Engineers, held in the Engineering Building in New York, had an extremely well filled program, not only of technical sessions but interesting social features and excursions. An extremely important Society action was the choice of C. E. Davies as Secretary of the Society. Mr. Davies has long been associated with the A.S.M.E. as Assistant Secretary and is therefore well qualified to succeed the late Calvin Winsor Rice, whose passing away during the past year was felt as a decided loss to the Society. A fitting tribute was made to Dr. Rice in a service held in the Auditorium of the building on Wednesday, conducted by Dr. John H. Finley, Editor of the New York Times.



Ralph E. Flanders, recently installed president of the A.S.M.E.

At the annual business meeting the new officers of the Society were announced, Ralph E. Flanders being elected as President for the coming year, has a background of machine design and construction experience followed by editorial work on Machinery, later becoming associated with Jones & Lamson Machinery Co., of which he is at the present time President. It is a rather fitting coincidence that at the annual dinner Mr. Flanders was the recipient of the 1934 Worcester Reed Warner medal of the A.S.M.E. for his contributions to a better understanding of the relationship of the engineer to economic problems and social trends.

The following vice presidents were elected by the Society: James H. Herron, president of the James H. Herron Company, Cleveland, Ohio; Eugene W. O'Brien, editor of the Southern Power Journal, Atlanta, Ga.; Harry R. Westcott, president of Westcott & Mapes, Inc., consulting engineers and architects, New Haven, Conn. Managers chosen were: Bennett M. Brigman, dean of the Speed Scientific School of the University of Louisville; Jiles W. Haney, professor of mechanical engineering at the University of Nebraska; Alfred Iddles, vice president of United Engineers & Constructors, Inc., Philadelphia.

THE ENGINEER AND RECOVERY

Tuesday evening was designated as President's Night when President Paul Doty delivered his address entitled The Engineer and Recovery, a challenge to the mechanical engineer. This address cited the advancements made in engineering and was designed to encourage men of the profession in continuing the advancement that has been made in past years. A few important paragraphs of his address follow:

"The mechanical engineer is professionally interested in aeronautics, fuels, hydraulics, iron and steel, machine shop practice, management of industries, materials handling, oil and gas power, petroleum, power equipment, printing industry, railroads, textile machinery, wood industries and process plants.

"Any national recovery program which will stimulate these professional divisions and activities and put people, men and women, back to work at their normal occupations and restore prosperity to the durable goods industries and to the nation is assured of the interest of the mechanical engineer.

"To the engineer work means the overcoming of resistance and if there be resistance to any program of national recovery therein is the challenge to the engineer to carry the program to success.

"In fuels the engineer sees a form of energy which may be converted into light, heat and power whether the fuel be solid, liquid or gasses. The conversion efficiency factor is the work of the engineer. The conservation of energy is the field of the engineer.

"National wealth is national prosperity. The potential water powers of the nation may become a source of national wealth with the application of hydraulic turbines.

"The so-called stainless or rustless steels when tested under service conditions were found to be corrodible though to a very much lesser extent of course

than plain steel. This condition is now fairly well understood with the result that on one hand the conditions under which high chromium steels do not stand up have been satisfied and second by the application of such additional materials as titanium, the intergranular corrosion of these steels have been inhibited and their field of usefulness greatly extended.

"With cheap and abundant power and with our growing knowledge of chemistry and metallurgy much progress has been made lately in material. Examples of large and important industries based on such developments are evidence of the further impetus to the recovery that can be given by engineers.

"In power equipment and generation progress has been made along two lines, one by increasing the size of units, the other is to increase automaticity of the plant and thus decrease operating costs without sacrificing efficiency. A third direction in which progress is looming is in the way of creating entirely new methods of power generation, such as power from atomic energy. This, however, is as yet only in the earliest stages of laboratory development.

"As a society we have set our financial house in order, a necessary prelude to any economic recovery. We have been engaged in a searching study of our objective, our organization and our program with the intention of giving greater effectiveness to our work as a professional society."

Prophets and Panaceas

The Seventh Henry Robinson Towne lecture on engineering and economics was delivered by Dean Dexter S. Kimball who chose as his subject "Prophets and Panaceas" some pertinent sections of his address being quoted as follows:

"Man in his long journey from savagery to civilization has never lacked for prophets and seers who could see, or pretended to see, what the future held for him. Every age has had its Jeremiahs, Ezekiels and Isaiahs, and these have always been particularly hopeful in times of depression such as this from the very beginning of the modern industrial era.

"The trouble with prophets of despair is that they never have all the facts in the situation.

"Human freedom is of three degrees, political, religious and economic, and the effort to attain some nature of such freedoms has been with man from the beginning and will follow him to the end.

"By economic freedom I mean freedom of all from poverty and all of its accursed results, freedom through the conquest of our material surroundings so that all men may live as men and not as beasts and freedom to enjoy at least some of the finer things of life free from the haunting fear of unemployment, want, hunger and the despair that has always been the lot of a large part of mankind.

"The average well being in this country in the early part of this century was probably the highest ever attained by any great civilized country and what we might have done with this power in times of peace we shall never know.

"It should be remembered that all advances whether industrial, political or religious, are, and always have been, accompanied by trouble and suffering. It appears to be inevitable that no great reform or betterment can be accomplished without suffering on the part of many. Make no mistake in this matter. If we shall achieve economic freedom, a high standard of life, security and delight in work and leisure, as we have to some degree achieved political and religious freedom, it will be through much trouble and against no little opposition.

"In any case we are due soon to find out how far we can legislate ourselves into prosperity or rather we shall find out perhaps how far we may assist natural economic laws through legislation. And the experience may be trying for many of us. The greatest difficulty with the economic prophet lies of course in his panaceas especially when they assume, as they often do, the form of legal enactments."

Technical Papers

From among the many technical papers and discussions presented during the meeting, abstracts are presented in the following paragraphs of those which, in addition to those published in the December issue of Power Plant Engineering, seem most pertinent to the power plant field.

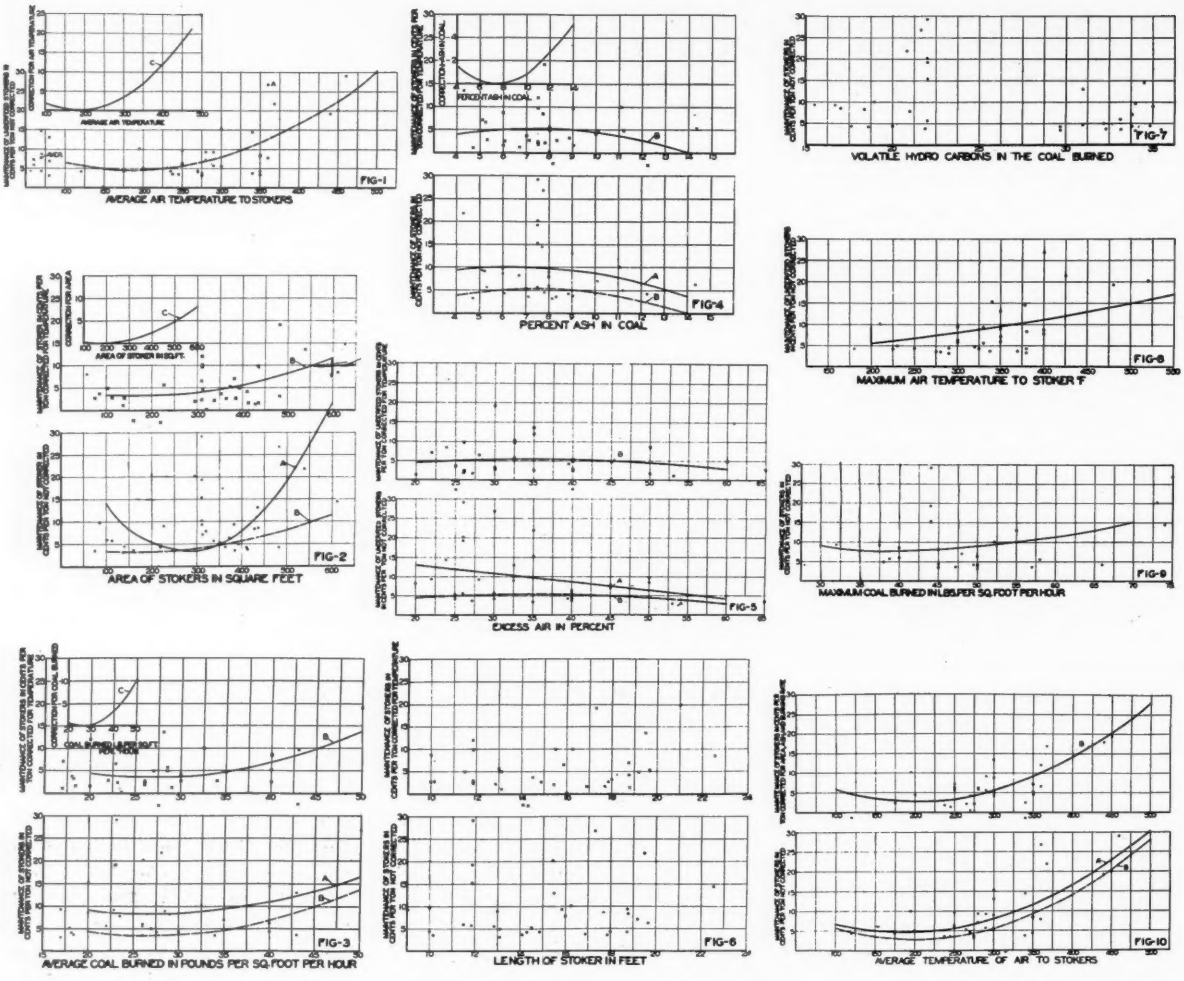
Performance of Large Journal Bearings, by R. Baudry and L. M. Tichvinski

Although the performance of journal bearings is usually calculated with the use of some of the numerous existing emperical data derived from past experience and tests, theory can be used for calculation of losses with a fairly close degree of accuracy, which was shown by the authors in tests made on 30 by 60 in. and 6 by 12 in. journal bearings. The coefficient of friction and the minimum oil film thickness of the journal bearing were shown to be nearly independent of the variation of unit clearance between rather wide limits, during which the bearing operates near the optimum condition of minimum efficiency of friction and maximum oil film thickness. The calculation of bearing performance is thus much simplified.

Effect of Skewing and Pole Spacing on Magnetic Noise in Electrical Machinery, by S. J. Mikina

Rotating electrical machinery over a wide range of speeds often leads to the emission of intense magnetic hum due to resonant vibration of the machine frame at some speeds in the running range. Due to the fact that the machine frame is capable of vibrating in a relatively large number of normal modes of vibration the probability of establishing a condition of resonance at least at one machine speed is quite high.

Any one of these normal modes may be excited under certain conditions. The author showed in this paper that, in cases where the electro magnetic disturbances arise from periodic vibration of magnetic reluctance between the poles and a slotted armature, it is possible to reduce the resultant exciting force on a frame to zero by suitable disposition of the field poles with respect to the armature or vice versa having regard both to the relative shapes of the poles and the slots and to the magnitude of the pole pitch.



Preheated Air Data presented in plotted form

Effects of Side Leakage in 120 Deg. Central Supported Journal Bearings, by Sidney J. Needs

Experiments, necessarily on a bearing of finite proportions and from which oil is leaking at the sides of the film, show results entirely different from those predicted by the theory which takes no account of side leakage. By means of a method developed and used by Mr. Kingsbury the paper presented by the author undertook an analysis of the effects of side leakage in a 120-deg. centrally supported journal bearing. The effect of side leakage was found to vary not only with the bearing dimensions of length and width but also with the load carried by a bearing of given proportions.

Results were given in tabular form and also by curves and from these optimum operating conditions were apparent. The problem of the best bearing for a given minimum film thickness, load, speed and journal diameter was treated, the only assumption being a desired average oil viscosity in the film.

Fluid Meter Nozzles, by B. O. Buckland

Description was given in this paper of a group of flow nozzles which has been used for the measurement of turbine condensate during performance tests and the results of calibrations of these nozzles were presented and compared with those of some other experimenters. These calibration results showed that the flow coefficients of all the nozzles of the group can be represented as a single function of the Reynolds' number with an accuracy of a little better than plus or minus one half per cent in flow coefficient.

The comparison of the calibration results with those of other nozzles shows that the nozzles with a gradual approach and an appreciable length of cylindrical throat have coefficients which change less abruptly with changing Reynolds' numbers than nozzles with rapidly curving approach and short parallel throat.

Economics of Preheated Air for Stokers, by Robert E. Dillon and Melvin D. Engle

Heat reclamation possibilities of the economizer have been reduced by the development of the regenerative cycle, the operation of boilers at higher and higher output and the adoption of higher pressures and the single pass boiler. This development has resulted in the installation of air heaters for most high efficiency steam generating units. Highly preheated air has increased the maintenance of underfeed stokers

beyond reasonable figures and it was the purpose of this paper to determine to just what extent stoker maintenance is a function of air temperature.

Data was secured from 33 companies operating all told 122 underfeed stokers and has to do with stokers using air with average temperatures varying from 120 to 460 deg. F. and maximum air temperature as high as 600 deg. F. Maintenance was plotted against average air temperature and a fairly satisfactory relation was found. In order to remove the influence of other variables affecting maintenance, stoker maintenance has been plotted against other operating and design factors and each corrected for temperature. From the data it was found that the variables other than average air temperature that most seriously affected maintenance are (1) area of stoker, (2) average coal burned in pounds per sq. ft. per hour, (3) per cent of ash in coal burned. From the results of the investigation the authors drew the following conclusion. Up to 300 deg. F. the preheating of the air supplied through underfeed stokers does not seem to increase maintenance above reasonable figures but above 300 or 350 deg. F. there is a sharp increase in maintenance with increase in air temperature.

Data were also obtained on the maintenance cost of 77 chain grate stokers supplied with hot air representing 440 stoker units of operation. When plotted, the data did not show any consistent relation between maintenance and average air temperature. A study of the data, it seems, however, would indicate that chain grate stokers supplied with hot air and burning the type of fuel for which they are suited can match the underfeed stoker in coal burning capacity in pounds per sq. ft. per hour and apparently operate with lower maintenance cost.

Discussion, High-Pressure-Steam and Binary Cycles, by G. A. Gaffert*

Performance figures given by the author, stated J. J. Grebe, check very closely the values which were published by Dr. H. H. Dow a number of years ago. He suggested that this study be continued to include a cycle in which mercury and a second fluid other than water be used.

In the opinion of A. G. Christy, a number of such plants will be constructed when the need next arises for added system capacity.

It was stated by Lucien A. Sheldon that the efficiency of any cycle depends upon the temperature range through which we work. In general the greater the temperature range, the better the efficiency. We cannot go beyond 800 deg. F. with diphenyloxide-steam cycle as this substance breaks down above this temperature. Mercury, however, is an element and does not break down at high temperature and approaches very closely the Carnot cycle in the application of power generation. From 5 to 10 lb. of mercury per kilowatt capacity is used at present but will probably be reduced to 4 lb. shortly.

*See December issue for abstract of paper.

Ten Years in Stoker Development at Hudson Avenue, by John M. Driscoll and W. H. Sperr

Hudson Ave. Station is a stoker fired generating station of 770,000-kw. rated capacity. It was started in 1922 with 14-retort underfeed stokers of 355 sq. ft. projected grate and ashpit area and completed in 1932 with an installation of 15-retort stokers of 694 sq. ft. projected grate and ashpit area. Development of the rated station capacity requires that the latter installation of stokers burn coal at the rate of about 65 lb. per sq. ft. per hr. using Eastern semi-bituminous coal of about 14,000 B.t.u. per lb. as fired. On test, coal was burned at the rate of 75 lb. per sq. ft. per hr. for 48 consecutive hours at a steam generating unit efficiency of 77 per cent.

During the development of this station five different types of stokers have been installed which were described and illustrated in the paper. The various steps in the development of the underfeed stokers to obtain the desired capacity were described and an apparent limitation in capacity of a purely underfeed stoker of any considerable length was discussed, as were also the unburned gas losses and the cinder losses in the heat balance of a boiler stoker test.

Coal Charges for Banking, Lighting and Burning Out Boiler Units, by George C. Eaton

This paper dealt only with the coal economics of various phases of boiler unit operation. Analyses of the banking, lighting and burning-out phases of operation were carefully described, these descriptions being illustrated by individual drawings. The boiler unit tested was a 14,479 sq. ft. Babcock and Wilcox, straight tube, sectional header cross drum boiler with integral convection type superheater set above a refractory lined furnace fired by a 13-retort, 25-tuyere Taylor stoker of 303.4 sq. ft. of projected grate area, equipped with a double roll clinker grinder.

The results of the banking tests show the following relation:

Hours from Start of Bank	Net Banking Charge lb. per hr. sq. ft. of Projected Grate Area
2.5	3.44
5	3.11
7.5	2.90
10	2.64
15	2.31
20	2.11
30	1.91
40	1.81

Lighting tests show a net charge of 76.0 lb. per sq. ft. of projected grate area, and the burnt-out tests a net credit of 54.8 lb. per sq. ft. of projected grate area.

Test Performance of Hudson Avenue's Most Recent Steam-Generating Units, by P. H. Hardie and W. S. Cooper

This paper presented the results of an acceptance test on one of the largest stokers in operation at the present time. The main purpose of the paper, how-

ever, was to illustrate the procedures developed for measuring those losses which are commonly allowed to appear in the unaccounted-for item of the energy balance. These losses are the hydrogen and hydrocarbon losses, and the carbon-monoxide loss which is in excess of that indicated by the conventional type of Orsat apparatus.

Usually, part of the cinder loss appears in the "unaccounted-for" because it is seldom determined with the accuracy which the magnitude of this loss as determined from the method described would seem to warrant. The completeness with which the losses were measured is evident from the low value obtained for the radiation and unaccounted-for item of the energy balance.

A high rate of combustion (75 lb. per hr. per sq. ft.) was carried for 48 hr. at an efficiency of 77 per cent. The superheater produced approximately constant steam temperature over the full range of loads.

Flow Distribution in Forced-Circulation Once-Through Steam Generators, by H. L. Solberg, G. A. Hawkins, and A. A. Potter

Forced-circulation once-through steam generators of large capacity are constructed of several parallel circuits connected between inlet and discharge headers. Unequal flow distribution between these circuits, possibly resulting in tube failure, may be due to unequal frictional resistances, unequal heat absorption, or improper arrangements of circuits. The investigation reported in this paper was undertaken in order to determine the effect of unequal heat absorption, unequal circuit resistances, and the location of equalizers upon the flow distribution in the circuits of forced-circulation steam generators.

Pressure-drop calculations were based on the measurement of friction factors of water at temperatures between 57 and 694 deg. F.; also of superheated steam at pressures between 1120 and 3578 lb. per sq. in. abs. with a maximum temperature of 806 deg. F. Head-loss measurements were made with a special glass manometer for pressures up to 2200 lb. per sq. in., and for higher pressures by radiographs of the mercury level in a steel-tube manometer.

An analysis of flow distribution between parallel circuits leads to the following conclusions:

(1) Parallel circuits connected between the feedwater header and the superheater outlet header are unstable, the pressure drop being nearly independent of the flow rate. Consequently, slight variations in frictional resistance or heat-transfer rates may result in decreased flow and in overheated tubes.

(2) The flow in unstable circuits can be controlled by the use of an inlet resistance such as a section of small diameter tube.

(3) The use of a common header or equalizer on each side of the evaporating zone will stabilize the flow in parallel circuits.

(4) Superheater and economizer circuits are more stable than evaporating-zone circuits.

(5) If only one equalizer is used, it should be placed at the end of the economizer section rather than at the end of the evaporating surface.

(6) The stability of circuits is independent of their capacity.

(7) The stability of superheater circuits is independent of pressure. Combined evaporating-zone and superheater circuits are more stable at high pressures.

Curves were presented to show the extent to which the enthalpy of the steam and of the water delivered from parallel circuits will vary as a result of unequal circuit resistances and unequal heat absorption.

The successful use of x-ray photographs in conjunction with a steel tube mercury manometer, in the opinion of H. J. Kerr, is a tool having interesting possibilities. He agreed with the authors that a unit designed with a separate drum at the end of the evaporator zone very much simplifies the problem of once through series boilers. This can be considered as the end point of the steaming economizer units, many of which are now in service and we have built and operated such units to the end point.

Dean Potter stated that the lack of values of viscosity of water and steam was the most difficult problem with which they had to contend during the conduct of the tests.

It was stated by J. J. Grebe that the Dow Chemical Works has had a once through boiler in operation for about a year, the feed pressure being 1750 lb. and the outlet steam pressure 1550 lb., making a drop of 200 lb. through the boiler. He does not consider that equalizers are needed in the operation of this boiler as the men in charge consider the control very good.

Pulverized Fuel Burning Experience, Buzzard Point Station, by H. G. Thielscher

The Buzzard Point Power Station of the Potomac Electric Power Co. exemplifies the latest trend in power station design. Steam conditions are 650 lb., 850 deg. F. The unit system of pulverized coal is used. Furnaces are completely water cooled with slag tap bottoms. 37,000 B.t.u. heat release in furnace at full load gives excellent results, combustible in fly ash averaging 12 per cent. Over size electrostatic precipitators recover practically all the fly ash.

Pulverizers show sustained fineness after grinding 25,000 t. of coal without replacement of wearing parts. Slag tapping has been accomplished with a minimum of labor. Unit system has shown a practical working range of 7 to 1. The steam generating unit embodies a method of controlling superheat to give a flat curve from 55 per cent boiler load up to 100 per cent. Monthly operating efficiencies of the unit are close to test guarantees showing the ability closely to control combustion and operation.

Overall plant performance was 12,672 B.t.u. per net kw-hr. for the six months, January to June, during the period of preliminary operation. The major operating equipment is confined to two floors, requiring a minimum of operating labor. The heat cycle was selected to give lowest costs, operating expenses and fixed charges considered.

A. G. Christie expressed surprise that the use of fluxing materials has not resulted in more fluid slag and suggested the use of limestone in lumps. It was notable he thought that heat release was higher than usual in the past and that no ill effects from bad slacking have been noticed.

In the opinion of E. G. Bailey two major problems present themselves when burning coal in pulverized form, the first being to burn practically all of the carbon in the limited space and time available and the second to dispose of the ash. He also noted that the heat release of 36,800 B.t.u. per hour per cu. ft. of total furnace volume is the highest yet obtained from low volatile coal.

Air-Flow in Fan-Discharge Ducts, by Lionel S. Marks

This paper was concerned with an examination of possible causes of the discrepancies which are sometimes found between pitot-tube measurements and nozzle measurements of the volume of air flowing in a fan-discharge duct. Among the conclusions reached are the following: (1) Air pulsations may cause a small error; (2) incorrect location of the outermost pitot-tube station results in an error of at least 0.6 per cent; (3) pitot-tube errors and non-axial flow are the principal sources of error.

This paper also gave the characteristics of various pitot tubes, showed that non-axial flow exists in the discharge from single-inlet centrifugal and propeller-type fans and indicated that this discrepancy can be eliminated by the use of egg-crate straighteners which it recommended for adoption in standard test practice. It was indicated, too, that the present standard length of test-discharge duct can be halved without loss of accuracy and the friction coefficient omitted.

It was recommended by the author, as a result of the study covered by this paper, that for test purposes the term "velocity head" should be redefined and that a more precise specification for the pitot tube should be adopted.

W. H. Carrier expressed the opinion that Mr. Marks' investigation gives confidence to the use of pitot tubes in making air flow investigations. He also stated that only improvement in fan practice and fan design would result from adopting the suggestion of Prof. Marks that static pressure readings be taken one diameter from the fan discharge.

Avid Pearson brought up the question, why not specify flow nozzles in the test code on fans. If the fan is of such size that the expense of the test set up becomes prohibitive, test of a model may be resorted to as is done in hydraulic practice.

Recommendation was made by J. F. Downie Smith that substantially the following be included in the test code: (1) calculate the volumetric discharge by averaging the velocity as specified in the test codes; (2) calculate the velocity head of the discharge by averaging the velocity heads obtained at the several specified test points.

R. D. Madison commended the use of honeycomb straighteners with short test duct. The subject of the use of rectangular ducts, he thought, was too quickly dismissed by the author without considering some of their advantages.

H. F. Hagen stated that he had been led to the reasonable conclusion that no general calibration of types of pitot tubes can be accurate. There must be a calibration of the individual tubes. He stated his preference for the use of nozzles as compared with pitot tubes.

A new definition of velocity head is needed in the opinion of Ed S. Smith, Jr.

A Critical Summary of Published Information Relating to the Embrittlement of Boiler Steel, by Everett P. Partridge and W. C. Schroeder

Much information has been published during the two decades since the first investigations of embrittlement of boiler steel. The survey paper of this information was divided into four parts, dealing respectively with the fundamental chemical reaction between iron and water and the effect of various dissolved substances on this reaction; the mechanical properties of steel after exposure to chemical attack; the effect of temperature upon the mechanical properties of steel; and the combined effect of mechanical stress and chemical attack upon steel at boiler temperatures.

The products of the fundamental reaction between iron and water are hydrogen and the black magnetic oxide of iron. The latter is deposited on the surface of the iron as a coating which tends to stop the reaction. The effect of different dissolved salts may be interpreted in terms of their effect on this oxide coating.

In addition to the possible selective corrosion of steel by the constituents of boiler-water salines, the hydrogen resulting from the reaction of water with iron may cause an embrittling action.

With increase in temperature up to approximately 250 deg. C. (482 deg. F.) steel becomes progressively stronger and less ductile. This effect of temperature must be considered in relation to the other factors in embrittlement.

The magnitude of the stress necessary to produce embrittlement cracking is uncertain because of the possibility of non-uniform loading in the various investigations of the subject.

The Solubility of Sodium Sulphate in Boiler-Water Salines as Related to the Prevention of Embrittlement, by W. C. Schroeder, A. A. Berk, and E. P. Partridge

Since solid sodium sulphate is believed to inhibit the embrittlement of boiler steel, a knowledge of the conditions which will cause this substance to deposit from a boiler water during extreme concentration is desirable. The solubility relations of sodium sulphate in solutions of sodium hydroxide, sodium chloride, sodium carbonate, and sodium phosphate have therefore been determined over the range from 150 to 350 deg. C. (302 to 662 deg. F.).

The effects of the different substances upon the solubility equilibria of sodium sulphate are shown in the form of curves. In general, the amount of sodium sulphate, sodium carbonate, or sodium phosphate which can remain in solution decreases with increase in temperature and with increase in the concentration of other sodium salts. At high temperatures, however, both sodium chloride and sodium hydroxide tend to increase the solubility of the other sodium compounds.

Power Show Exhibits *indicate trends in* Perfection of Details

Instruments, Meter and Control Equipment Take Lead in Extent of Improvements. Metallurgical Developments Are Reflected in New Designs

OPENING Monday afternoon, December 3rd, the Eleventh Annual Exposition of Power and Mechanical Engineering had on display the latest types of all kinds of power equipment which are available to industry at the present time. There were some 225 exhibitors and during the six days of the exposition something in excess of 100,000 people passed through the doors. As might be expected, the equipment exhibited as new was principally designs of well tried equipment which has been improved by incorporating the new materials which are now available and the employment of scientific principles which have recently been worked out.

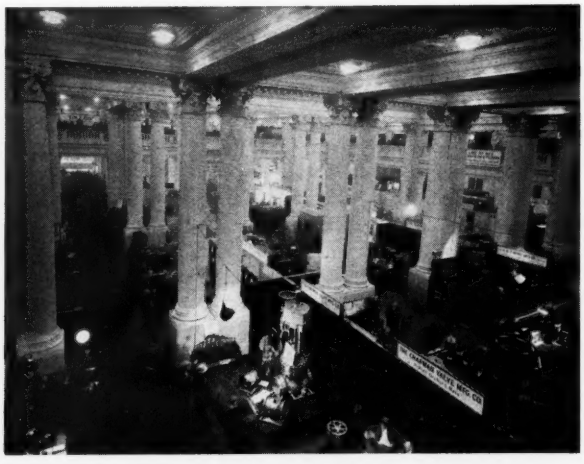
Probably the outstanding feature of the show was the evidence of advancement made in the design of instruments for operating, test and accounting purposes, many manufacturers having, during the past two years, completely redesigned their instruments to meet the growing need of the industry.

Combining three of the most important operating conditions so as to be indicated on one instrument, the Bailey Meter Co. exhibited for the first time its new steam flow, air flow and flue gas temperature meter. This device indicates and records steam flow, air flow and flue gas temperature and integrates the steam flow. Cutaway models showing the accurate, sensitive air flow mechanism and the powerful interchangeable head steam flow mechanism were on display. A Bailey meter air-operated combustion control system was in operation demonstrating the method by which the new Steam Flow-Air Flow Bailey boiler meter automatically maintains highest combustion efficiency consistent with economical operation.

Featuring power plant instruments of the indicating, recording and integrating type, Brown Instrument Co. had in its booth a number of panels upon which were mounted instruments of typical design used in power plants, such as CO_2 meters, resistance thermometers, with remote recording and integrating features especially convenient for the operating engineer. A feature of considerable interest was the multiple recording charts which the company supplies with resistance thermometers.

Measurement and control instruments for handling air, gas, steam and other liquids were displayed by the American Meter Co. in recording and totalizing designs.

Recent designs of meters were the features of especial interest in the Bristol Co. booth. Flow meters and metameters in recording, controlling and indicating designs were shown together with thermometers of the remote indicating type and the portable recording type.



A complete panel board of power plant instruments was exhibited in the booth occupied by the Cochrane Corp., Hays Corp. and Paul B. Huyette Co. Mounted on the panels were Cochrane flow meters and Hays draft gages and CO_2 recorders. The principal feature of this exhibit was the Cochrane electric flow meter which is one of the corporation's most recently developed products. The Hays Corp. took this opportunity to announce the new Hays combustion test set, designated as Series 3000.

All-steel gages of the indicating and recording type, obtainable in all ranges of pressure, were featured by the Crosby Steam Gage & Valve Co. and are particularly suitable for steam and water. Various types of gage testing apparatus were also shown. Of particular interest were the safety and relief valves which are now being made of alloy steels suitable for the highest pressures and temperatures used in industry.

At the booth of the Ellison Draft Gage Co., the new design of CO_2 hand analyzer which has recently appeared on the market was especially interesting. This new design is the result of development over a long period of years and each detail has been worked

out to give long service, convenience and accuracy. Problems of corrosion and the danger of breakage have been well met in this new design. Other features of the exhibit were the straight line draft gages, steam calorimeters, pointer draft gages, manometers and inclined tube draft gages.

With a complete line of power plant instruments on exhibit, many of them of new design, the Foxboro Co. called particular attention to the flow meter with straight line chart. Instruments mounted on the panels included pressure gages and thermometers, of both indicating and recording types, many of them in the small size, which is becoming popular in power plants. The Rotax humidity controller, indicating pyrometer with selector switch, Stabilog temperature, pressure or flow controller were included in the exhibit.

Having the quality of accuracy comparable to laboratory precision instruments was the line of control instruments featured by the Leeds & Northrop Co., particular attention being called to the new a.c. type Micromax round chart pressure recorder which operates entirely on 110 v. 60-cycle current. Other features of the exhibit were the frequency indicating recorder, frequency control and multicolor recorder, which is especially useful when several points fall close together on the chart. Two new instruments having to do with chemistry in the power plant were the dissolved oxygen detector which indicates and records the amount of oxygen in feedwater which involves the use of the photo cell principle and the pH indicator which employs a glass electrode assembly and duplex galvanometer giving the potential difference and registering pH values. Also on exhibit were combustion control instruments that actuate partly by air and partly by electricity and employ push button stations built into cases to provide both automatic and centralized push button control at the boiler panel.

In the booth of the Republic Flow Meters Co. and its subsidiary, the Smoot Engineering Co., was shown a rather complete line of control equipment of the most modern design. It included a Smoot Master Controller for regulating combustion in boiler furnaces and several panels upon which were mounted flush front instruments used for the control of a four-boiler plant. This control may be set for either manual or automatic operation of any of the boilers or for constant rating of any boiler with automatic operation for the others, making it a very flexible control unit. What is designated as the Series 50 control, used for boilers of 500 hp. and lower, and operated by oil, water or air pressure, was also on exhibit. There was shown a number of combination flow meters mounted in panels which indicate steam, air, CO_2, water and blowdown, all in one instrument with horizontal dials. Instruments recording on multiple strip charts various operating conditions were a feature of the exhibit as was also the new Republic mechanical flow meter of the indicating and recording types.

Using the Tag indicating potentiometer controller in actual service on an electric furnace made an attractive exhibit in the booth of C. J. Tagliabue Mfg. Co. Features of this controller are the substitution of a light beam for an indicating pointer and use of a photo cell and a mercoid switch to control the actuating electric circuits. Other instruments shown were multiple temperature recorders capable of recording the temperatures of from 1 to 12 points on one chart, viscosity meters, pyrometers and portable electric moisture meters applicable to lumber, grains and coal.

In the metallurgical line, the exhibits of the International Nickel Co. were indicative of the progress which is being made. In this booth were monel metal which is a composition consisting of two-thirds nickel and one-third copper used extensively where resistance to corrosion is an important factor. There was also on exhibit ferrous nickel alloys and nickeled bronze, the latter particularly adapted for bearings supporting heavy loads and other applications where corrosion and wear must be resisted. Such parts as turbine blades, bearing linings, gears, valves and fittings made of these metals were shown.

Boiler Room Accessories

New features of design which were exhibited in the booth of the Buffalo Forge Co. were the intake chutes with fixed inlet vanes for induced draft fans which, it is claimed, prevent overloading of the fan during operation. Another detail was the floating base for fans which prevents vibration from being transmitted to the fan supporting structure This consists of a specially designed rubber pad in which the rubber support is under continuous sheering stress. Also of interest were the several types of unit heaters which the company has developed.

An actual demonstration of remote reading pressure gages was made in the booth of Consolidated Ashcroft Hancock Co. Other products shown were recording thermometers, recorder controller for temperature or pressure and considerable prominence was given to safety and relief valves.

Prominent in the exhibit of Yarnall-Waring Co. was the new high and low alarm water column recently put on the market by this company. The gage glass attached to this column is inclined so as to be conveniently visible to the operator. Especial emphasis, however, was given to the many important features of blowoff valves made by this company to meet all conditions under which boilers are operated from the lowest to the highest pressures in industry. Of particular interest was the display of valve plungers in different metals and sizes employed in the design of blowoff valves, bronze suitable for 250 lb., Ambrac for 250 lb. pressure where the conditions are very bad, and Nitraloy suitable for pressures ranging from 450 to 1500 lb. and for very severe blowoff conditions. One design displayed employs a by-pass around the main blowoff valve, in which is placed a smaller valve that discharges at a lower rate and is convenient for lowering boiler water concentration.

Outstanding among the products exhibited by the Foster Engineering Co. was the automatic damper regulator which is directly connected to dampers or to valves of the fan engine to provide close control over steaming operations. It is water actuated and suitable for water pressures between 25 and 75 lb. and for steam pressures between 10 and 300 lb. In addition to this automatic valves for all purposes were exhibited at the booth.

Along with the Thermix air heater and induced draft fans, the Prat-Daniel Corp. exhibited its new Thermix venturi dust trap which consists of a series of venturi shaped passages through which the gas or air passes horizontally. These passages vary in number and extent from the bottom of the duct to within a short distance of the top. The gas or air is speeded up as it approaches the slots along the sides of the throat and the momentum of the dust particles causes them to concentrate along the converging walls of each passage where they are caught in the slot and retained in the dust chamber. The gas then strikes the next set of converging walls and the same result occurs. The retained dust then falls by gravity to a hopper at the bottom of the apparatus.

Hydrecon is the trade name of a new refractory developed by J. H. France Refractories Co. which has unique features applicable to many uses around industrial and boiler furnaces. Hydrecon is a monolithic refractory which in applying is mixed with water and poured into place without ramming. It sets by crystallization and is suitable for working temperatures up to 3200 deg. F. In addition to this product the company exhibited a full line of fire brick which is made up in all shapes and forms.

An entirely new design of underfeed stoker built into capacities from 500 to 1250 lb. of coal per hour, was the feature of principal interest in the booth of Iron Fireman Mfg. Co. This stoker feeds the coal from the hopper to the retort with a screw conveyor and distributes the coal in the retort by means of an oscillating ram. The stoker is manually adjusted through a train of gears for three speeds supplemented by automatic off-and-on control of the driving motor which is under the control of the boiler pressure. Forced draft air control is also automatic, making a unit of high efficiency applicable to small boilers.

Water treating chemicals for boiler feed purposes were discussed with visitors at the booth of the National Aluminate Corp. whose policy is to recommend what they consider the best treatment for the water available at the plant. This company insists on the routine testing of feedwater and boiler water in the operation of boilers and has developed for this purpose a convenient plant kit which can be operated by the man in charge of the boiler plant.

Of particular interest in the booth of the Permutit Co. was the automatic Zeolite water softener which is electrically operated under the control of the water meter so that it goes through all the operations of recharging without attention from an operator when predetermined amounts of water have passed through the softener. Other industrial and household softeners were on display as was also the Multiport valve used with water softening units, which displaces from five to nine valves with a single unit. Heat exchangers of the industrial plate type used quite extensively in conjunction with continuous blowdown systems were also on display. The latest type of Ranarex CO_2 indicating and recording meters were shown mounted on panels as well as in cross sections and a new product of the company, designated as the Permutit Electro Chemical Feed Control Unit, for use with lime soda plants, was made a feature of the exhibit.

Piping, Valves and Traps

The most prominent feature of the American Brass Co. exhibit was a display of Anaconda extruded, drawn and rolled condenser tubes in both standard and special alloys such as super nickel and ambrac. Anaconda deoxidized copper tubes and fittings, both solder and flared types, for innumerable applications such as conveying water, gas, oil, air and steam, were shown and their assembly demonstrated.

The growing use of stainless steel for valves and fittings was called to attention by the exhibit of Crane Co. with a complete new line of anti-corrosion stainless valves and fittings suitable for handling special fluids and gas. Other features of the exhibit were the Series 40 motor operated gate valve, welding fittings, inverted open float steam traps and brass and forged steel valves in all sizes.

Featuring an improvement in design features of its valves, the Fairbanks Co. laid special emphasis on the improved bronze globe and angle valves, calling attention to such outstanding features as the deep stuffing box with follower gland, protected top seat when packing under pressure, an increased number of spindle threads in contact with the bonnet, two-piece bronze union bonnet and nut, slide-on disc holder with guides, and the renewable disc ring. Besides these valves of new design, a full line of standard valves was also shown.

The new Genspring industrial high pressure power piping hanger was the principal feature exhibited by the Grinnell Co. which is designed to remove strains in the piping due to weaving of structural piping supports. This new design is an addition to the complete line of pipe hangers which were also shown. Another new product exhibited was the Thermolier, an air conditioning type of unit heater recently developed. A complete line of welding fittings was also shown.

"Jenkins valves on parade" was an unusual exhibit of the full line of small valves manufactured by Jenkins Bros. arranged to travel across a panel, making a fascinating exhibit. The newest products featured were the regrind, packing renew, globe and angle valves, which are designed with renewable nickel alloy seat rings and discs, suitable in the screwed designs for pressures of 300 lb. steam or 500 lb. oil, water or gas working pressure and in the flanged designs for 250 lb. steam or 400 lb. oil, water or gas working pressure.

Special attention was given in the booth of the Lunkenheimer Co. to 1500 lb. motor operated gate valves, one being operated by Cutler-Hammer control, the other one by a Limitorque device. These valves are suitable for 750 deg. steam temperature when made of carbon steel and 900 deg. when of alloyed steel. There was also exhibited a new design of 400 lb. steel gear operated non-return valve. A full line of welding end valves and an exhibit of welded fittings tested to destruction were also shown. In making up these connections electrodes of special metals are used for each grade of metal in the pipes. The booth was made attractive by a full line of bronze, iron, all iron and anti-acid valves.

Pressure, temperature, flow and liquid level control

valves made up the display of the Mason-Neilan Regulator Co. which included the latest designs of balanced valves, pump governors and reducing valves.

William Powell Co. made a feature in its exhibit of a line of iron, bronze and steel valves with Stellite facings. These new products have application in high pressure and high temperature steam plants where the temperature is above 750 deg. F. They have special application in industrial plants handling high temperature liquids and where valves are required for throttling service.

Pipe threading tools of various models were shown in actual work demonstration by the Toledo Pipe Threading Machine Co. which has recently placed on the market the improved 2-in. power pipe machine designated as No. 999 and having many convenient features, such as quick opening die heads and dies.

Vogtalloy valves were featured by Henry Vogt Machine Co., these new valves being developed for pressures in the range of 1350 lb. and 750 deg., and applicable to steam, water and gas, and built in gate, globe and slide types. A feature of particular advantage is that this metal does not creep appreciably in high temperature service. Other features of interest were the butt welded Series 30 valves having the flanges butt welded to the body. Also stainless steel lined flanged gate valves, designed especially to resist corrosion and erosion, were on display. Complete lines of drop forged steel valves and fittings and all stainless steel valves were shown.

Among the exhibits in the field of piping was that shown by Walworth Co. which featured the Walseal fittings made of bronze and steel. These employ a ring of SilFos, a patented silver solder which takes the place of threads, the sealing being done by means of an acetylene torch. It was explained that this type of bronze fitting is suitable for temperatures as high as 450 deg. F. and steel fittings for temperatures of 550 to 600 deg. F., the pressures being limited by the metal rather than the solder used for sealing. For the Walseal high hub flange, the solder is inserted in a groove in the hub of the flange and the flange does not have to be re-faced after making the joint because the heat is applied only to the outer end of the high hub.

Several devices of new design were shown in the booth of Wright-Austin Co. among them being the automatic boiler feeder which is designed to maintain normal water level in low pressure boilers. There was also shown an Airxpel steam trap suitable for 125 lb. pressure which has been designed in smaller size within recent months. The Plainsite incliners which are used on the water columns of tall boilers adjust the gage glass to an inclined position, making the water level visible from the firing floor, were a feature of the exhibit, also the new gage glass light which employs a Neon tube directing a line of light upon the gage glass, the effect of which is to make the water in the glass more visible to the operator.

Trap action shown by means of a glass model operating under 5 lb. pressure was the attractive feature exhibited by the Armstrong Machine Works, which also called attention to the chrome steel heat treated valve parts used in Armstrong traps built for pressures ranging from zero to 1800 lb.

Stated to be the hardest material ever produced by man for commercial use, the Norton Co. exhibited samples and products made from Norbide, a boron-carbide product whose applications have not been fully developed but at present the material is used for the linings of sand blast nozzles. Another product exhibited was Crystolon, a silicon carbide compound in brick form, used extensively in furnace walls along the clinker line, as it is non-porous and clinker will not adhere to it.

Air conditioning by means of a chemical was a feature of the exhibit by Research Corp. which had on demonstration the calorider system of humidity control by means of which humidifying is accomplished by passing the air successively through sheets of tempered water. This washes the air free of dust and objectionable odors and in the final stage the air passes through a filter composed of the chemical salt called Caloride which is dissolved by the moisture in the air thus delivering the air dry to the industry or room where moisture is to be controlled. Other features of the exhibit were the Cottrell electrical precipitator, an inertia impact classifier, a multicone collector to remove dust from gases, and a Coey multistage cooling tower.

The action of thermostatic elements of steam traps was demonstrated in the booth of Sarco Co. by means of a revolving wheel on the periphery of which was mounted a series of these thermostatic elements. The wheel was kept in motion by the alternate condensation and the evaporation of the contained fluid affected by means of a stream and an air jet. It was announced at the booth that Sarco traps have had new designs added fitting them for higher pressures which are coming into industrial use.

Eagle "66" furnace insulation was the most recently developed product on exhibit by the Eagle-Picher Sales Co. and is recommended for low temperature application such as breechings and heaters. This cement is a rock wool plastic product for temperatures in the neighborhood of 1800 deg. Eagle "33" is the product recommended for piping, boilers and furnaces. The company also exhibited Eagle "77" pipe insulation which is made up in forms and Eagle "88" which is a metal jacketed pipe insulation finding considerable application in industries.

Among the new products exhibited was Bacite, recently put on the market by the Bird-Archer Co. This new insulating material is a special clay product suitable for use on boiler walls, tanks, heaters, etc., where the temperature may run as high as 1600 deg. F.

In the insulation field Keasbey & Mattison Co. exhibited an 85 per cent magnesia pipe covering which is now marketed in sectional forms for 12-in. pipe of half sections, the former product being in four segments. Another new product of the company on exhibit was Amroc cement, blanket, loose and granulated, this being a rock wool product suitable for temperatures of 1600 deg. F. A new type of welding rod which is used in electric welding was also shown. It is covered with blue asbestos yarn which forms a flux during the welding process.

Special attention was being given to Transite pressure pipe which is one of the new products of Johns-Manville Corp., being made of asbestos fiber and

portland cement for use in conveying liquids such as water, oil, acids, etc., taking the place of cast iron in many instances. This piping is used in hot water heating systems or in industrial plants where the liquid temperature does not exceed 600 to 800 deg. Another feature of the exhibit was a full line of asbestos products in which the company specializes.

Prime Movers and Power Application

Considerable interest was shown by visitors in the crackless Diesel engine exhibited by the Sterling Engine Co. This new type of engine has recently been put on the market in capacities ranging from 50 to 700 hp. The unit was shown with a glass panel which made the principles of operation plainly visible. A Sterling Viking gasolene engine was also on exhibit, units of which are built in sizes from 425 hp., 900 rpm. to 565 hp., 1200 rpm. A new device exhibited by the company is called the Flo-rator which is a combination instrument and control device that will indicate the measured rate of flow of any liquid or fluid having a variable viscosity characteristic and when applied as an automatic unit, the Flo-rator will control a viscosity condition to any desired degree. It is particularly applicable to fuel oil used for firing boilers and heaters, or going to oil engines.

In the booth of the Waukesha Motor Co. two complete engines were shown, one being a low compression oil injection engine with spark ignition, built in six-cylinder units, which are manufactured in sizes that range from 20 to 170 hp. The other unit shown was the new Waukesha steam engine of the uniflow type with four vertical cylinders, which is built in sizes from 100 to 150 hp. and runs at 900 rpm.

In the booth of the Condenser Service and Engineering Co. and its subsidiaries, Blackburn-Smith, Instrument Service, and Molten Metalizing Corp., were shown a line of industrial thermometers, filters and strainers, heat exchangers and a wizard condenser injector for condensers, the latter being a new product which applies a sealing compound on the water surface of a condenser while the condenser is in service. There was also shown and demonstrated a condenser packing tool which applies corset lacing packing at a great saving of labor. A demonstration was also carried on of metal spraying equipment.

Illumination

High intensity mercury vapor lamps rated at 400 watts, 35 lumens per watt, used principally for industrial purposes, were featured by the General Electric Co. Application of the Thrustor, which finds use in power plants for operating valves, ash dumps and hoists, was demonstrated by a unit of 800 lb. capacity with a controllable feature for slow or fast operation. A quiet-operating a.c. contactor which employs a rectifier to supply d.c. for holding the contacts in position, finds application in some installations where quiet is a necessity. Another product shown was the G. E. gear-motor, which is a combination of motor and reducing gear in one unit and may be built for ratios as high as 150 to 1 speed reduction.

A new variable speed chain drive developed by the Link Belt Co. and designated as VRD is a mechanical speed selector with which it is possible to obtain an infinite number of speeds easily and quickly while the machine is in operation, the driving chain being fitted with side rollers which contact cone-shaped pulleys. This new drive is a modification of the company's PIV gear which has been on the market for some time. The other new drives exhibited were the silent chain drives with textile cases that are strictly oil tight and a motorized speed reducer employing helical gears.

A feature of particular interest exhibited by Reeves Pulley Co. was a new product designated as the Hydraumatic control for the standard Reeves variable speed transmission, used for synchronization of units or for automatic speed regulation of any device such as stokers in conjunction with pressure regulators. Other features of the exhibit in this booth were various types of standard Reeves transmission apparatus.

A miniature rolling mill in operation at the booth of Youngstown Sheet and Tube Co. was an attractive exhibit which was supplemented by colored pictures illustrating steel mill work.

Lubrication

Lubricants produced by the new Clearosol process were featured by Socony-Vacuum Oil Co. This process separates paraffine and naphthalinic constituents in the production of lubricating oils which are used extensively in power plants for internal combustion engines and steam turbines. A feature of the booth was the miniature bubble tower which illustrated the scrubbing process.

An attractive method of illustrating the viscosity of various lubricating oils manufactured by the Texas Co. was a revolving disc mounted upon which were tubes containing the various grades of oil through which air bubbles were caused to rise, their rapidity of travel being a function of the relative viscosities. Another attraction in the booth was a miniature machine shop.

Lubricating oil systems were the specialty Hills-McCanna Co. displayed in its booth. Oil pumps for feeding all the bearings of an engine drop by drop from one unit, on in sizes up to pumps that handle large quantities for some industrial purposes were shown in operation.

To prevent oil leakage from shaft roller or ball bearings the Garlock Packing Co. has developed a new product known as Garlock Klozure, which is a built up ring of special oil resistant material which contacts revolving shaft retained by a metallic casing so designed as to maintain the desired pressure against the shaft. Other products exhibited were the standard Garlock line.

Notable use of nickel alloys in power equipment of recent plants is as grout stops for expansion joints and seals between concrete blocks at Boulder Dam, also as valve seats for water gates, in the big butterfly valves, for nuts, bolts and sheds of gate and needle valves and in shafts for rope sheaves and for tower track wheels of the cableways. At dam No. 2 on the Kanawha River, many tons of nickel steel have been used as bolts, and as castings for bulkheads, gate valves and pintles.

News From the Field

FRED J. WALLS has joined the development and research staff of International Nickel Co., Inc., to concentrate on nickel cast irons for wear resistance. Mr. Walls, after specializing in metallurgy at the University of Michigan, was for 18 yr. with Wilson Foundry & Machine Co., Pontiac, and later with Eaton Erb Co. in Detroit. He has been active in the American and Detroit Foundrymen's Associations and in the American Society for Metals.

THE BROWN INSTRUMENT CO., Philadelphia, Pa., announces a consolidation with Minneapolis-Honeywell Regulator Co., Minneapolis, Minn., in which The Brown Instrument Co. will continue as a separate company with its existing organization but as a subsidiary of Minneapolis-Honeywell Regulator Co. Richard P. Brown will continue as president of The Brown Instrument Co. and will become an officer and director of Minneapolis-Honeywell Regulator Co.

The Brown Instrument Co. sales and service facilities will be continued from the present main office and factory at Philadelphia and the district offices located throughout the country.

AMERICAN DISTRICT STEAM CO., North Tonawanda, N. Y., has appointed Tomlinson-MacLachlan, Inc., Cleveland, Ohio, as exclusive sales agents for the company for Cleveland and Northeastern Ohio territory to handle the sales of expansion joints, condensation meters, steam flow meters, water heaters, steam traps, reducing valves, vapor heating specialties, underground steam line conduit and insulation and other kindred equipment.

ROBERT G. HUNT, vice-president of Byllesby Engineering and Management Corporation and Standard Gas and Electric Company, retired on December 1 after thirty-nine years of service. Mr. Hunt will make his home at Griffin, Ga., about forty miles south of Atlanta.

READING IRON CO. announces the following promotions and additions to its sales force: With headquarters at 401 No. Broad St., Philadelphia, C. T. Ressler, formerly manager of railroad and marine sales, is appointed Specification Engineer of the sales division; R. I. Fretz, formerly district sales representative at Columbus, O., is appointed Manager of eastern railroad and marine sales. C. W. Guthrie, formerly salesman in New York City, is appointed Sales Representative for the Columbus, O., territory. Bryant Myers joins the Pacific coast sales force with headquarters in San Francisco, E. S. Morrow, joining the oil country sales force will work under N. R. Putnam at Tulsa, Oklahoma. F. B. Olcott, appointed Special Representative for handling government business, will have headquarters in Washington, D. C.

HEMPHILL DIESEL engineering schools has established a branch in Chicago at 1253 Diversey Parkway for operators of Diesel engines, with initial capacity for 200 students. Ralph Hemphill, president has schools in Vancouver, established 6 yr. ago, in Los Angeles with 300 students and in Seattle with 100 students. Large equipment of engines has been purchased for the use of students in the Chicago school.

OSTER-WILLIAMS of Cleveland, Ohio, has just opened an office and display room at 292 Lafayette Street, New York City. The establishment will be in charge of the firm's district manager, H. B. Van Osten. The display floor will have on it, one each of practically every type of machine and tool manufactured by Oster-Williams.

AS PART OF its assistance to its staff of field engineers, Standard Oil Co. of Indiana is issuing a monthly bulletin as a clearing house for ideas on unusual lubrication problems that have been met and solved and for suggestions on puzzling problems that are seeking solution. This forum for exchange of practical ideas gives an additional tool to the staff, which in addition to the company's technical department and its Whiting laboratory are constantly working out new applications of products and developing new products to increase economy and efficiency and to meet new needs in lubrication.

SIEMENS, INC., 75 West Street, New York City, has been formed to act as representatives of Siemens & Halske and Siemens-Schuckertwerke in this country. Dr. M. H. Weldhausen, president, and H. W. Gottfried, vice-president of the new corporation, will be in charge of their activities. Dr. K. G. Frank, former general representative of the two German companies, has retired.

A. J. WADHAMS, manager, development and research, The International Nickel Co., Inc., has announced the addition of David M. Curry to the development and research staff with headquarters in New York and devoting his time to development work in the non-ferrous casting field. For 11 yr. Mr. Curry was associated with the Ford Motor Co. and supervised the production of all non-ferrous castings used.

ORDERS FOR 30 large Diesel engines to be installed in 5 new submarines has been placed by the U. S. Navy with Fairbanks, Morse & Co. Twenty are for propulsion and 10 for auxiliary service. All are of light-weight, high-speed type, 8 of the larger and 4 of the auxiliaries having two opposed pistons, upper and lower in each cylinder, connected to crankshafts above and below.

Acknowledgement

ADEQUATE INSTRUMENTATION has been one of the major factors in the remarkable advancement of the power plant. As the eyes and ears of the engineers, instruments have guided performance, maintained standards of service, disclosed hidden losses and pointed out paths to improvements. Responsibility for developing these instruments was thrust upon manufacturers. They accepted the responsibility, and, taking the elementary and temperamental instruments from the sheltered and protected research laboratory, turned them into rugged, reliable and indispensable parts of the power plant. Without the whole-heatred assistance of these manufacturers this issue could not have been prepared and we gratefully acknowledge their assistance. In particular, are we indebted to the following concerns, some of them manufacturers of instruments, some of them manufacturers of other equipment which makes extensive use of instruments, from whom specific aid has been secured:

Allis-Chalmers Mfg. Co.
American Blower Corp.
American District Steam Co.
American Meter Co.
American Temperature Indicating Co.
Bacharach Industrial Instrument Co.
Bailey Meter Co.
James G. Biddle Co.
Borden Electric Co.
The Bristol Co.
The Brown Instrument Co.
H. A. Brassert & Co.
Buffalo Meter Co.
Builders Iron Foundry
Byron Jackson Pump Co.
Diesel Engine Co.
Busch-Sulzer Bros.
Cambridge Instrument Co., Inc.
Chain Belt Co.
Cochrane Corp.
The Columbia Electric Mfg. Co.
Condenser Serv. & Eng. Co.
Crocker-Wheeler Elec. Mfg. Co.
Crosby Steam Gage & Valve Co.
F. W. Dwyer Mfg. Co.
Detroit Lubricator Co.
Detroit Stoker Co.
Elgin Softener Corp.
Ellison Draft Gage Co.
Charles Engelhard, Inc.
The Esterline-Angus Co.
Fisher Governor Co.
The Foxboro Co.
Frick Co.
Julien P. Friez & Sons, Inc.
General Electric Co.
The Hays Corp.
Henszey De-Concentrator Co.
Paul B. Huyette Co.
Illinois Testing Labs. Inc.
The Jeffrey Mfg. Co.
Leeds & Northrup Co.
The James Leffel & Co.
The J. E. Lonergan Co.
McIntosh & Seymour Corp.
T. W. McNeill Engr. Equip. Co.
Mason-Neilan Reg. Co.
The Meriam Co.
Metric Metal Wks.
Morey & Jones, Ltd.
The National Superior Co.
Neckar Water Softener Corp.
Northern Equipment Co.
Norton Electrical Instrument Co.
The Palmer Co.
Palmer-Bee Co.
The Permutit Co.
Pittsburgh Equitable Meter Co.
Reliance Gauge Column Co.
Republic Flow Meters Co.
Richardson Scale Co.
Ruggles-Klingemann Mfg. Co.
Rochester Mfg. Co., Inc.
Sangamo Electric Co.
Schutte & Koerting Co.
Simplex Valve & Meter Co.
Spanner Vapor Lamp Co., Inc.
Stephens-Adamson Mfg. Co.
Sterling Engine Co.
Strong-Scott Mfg. Co.
The Strong, Carlisle & Hammond Co.
C. J. Tagliabue Mfg. Co.
Taylor Instrument Cos.
Thwing Instrument Co.
H. O. Trerice Co.
Uehling Instrument Co.
Westinghouse Electric & Mfg. Co.
Weston Electrical Inst. Corp.
Winton Engine Corp.
Yarnall-Waring Co.
O. Zernickow Co.

Power Plant Construction News

Ark., Fort Smith—Ozark Distillers Co., Fort Smith, care of A. S. Bullock, Fort Smith, head, recently organized, plans installation of electric power equipment in new distillery and winery. A boiler house will be built. Entire project will cost about $85,000.

Ark., Pine Bluff—Arkansas Power & Light Co., Pine Bluff, is considering extension in transmission lines to rural districts, for service at McArthur, Kelso and vicinity; also for new transmission line with power substation facilities from McGehee to Watson, Ark. Cost over $75,000. Company engineering department in charge.

Calif., Alameda—McClintic-Marshall Corporation and Bethlehem Shipbuilding Corporation, affiliated interests, plan installation of electric power equipment in connection with rebuilding of joint plant, recently destroyed by fire. Loss over $400,000, with machinery. Companies are subsidiaries of the Bethlehem Steel Co., South Bethlehem, Pa.

Calif., Burbank—Warner Brothers-First National Studios plan installation of electric power equipment in connection with proposed rebuilding of motion picture studios recently destroyed by fire. Loss over $300,000.

Calif., Torrance—City Council will take bids early in January for new motor-driven pumping machinery with capacity of about 2,000,000 gals. per day for municipal waterworks. Also for a new 250,000-gal. elevated steel tank on 150-ft. steel tower. F. B. Leonard is city engineer.

Colo., Denver—Bureau of Reclamation, Denver, will receive bids until January 21 for five excitation cubicles with equipment, two miniature-type main control boards and auxiliaries, three annunciator systems, four auxiliary control boards with equipment, four terminal boards with equipment, six 250-volt d.c. distribution switchboards, two 460-volt power boards, five thermal panels, miscellaneous 2300-volt and 16,500-volt switching, relaying and metering equipment, and other electrical equipment for Boulder Dam hydroelectric power station, Boulder Canyon project, California-Arizona-Nevada (Specification 601).

Del., Lewes—Consolidated Fisheries Co. plans installation of electric power equipment in connection with rebuilding of portion of cannery and packing plant, recently destroyed by fire. Loss close to $150,000, with machinery.

Fla., Hialeah—Hialeah Brewery, Hialeah, recently acquired by E. C. Barr and associates, plans installation of power equipment for expansion and completion of new brewing plant, on which work has been inactive for number of months. Cost close to $70,000.

Ind., Richmond—Indiana Gas Utilities has taken out a permit for new one-story boiler plant at gas-generating works. Cost about $25,000. Fallon & Mills, and J. R. Kelley, First National Bank Building, are architects.

Iowa, Dubuque—Dubuque Packing Co., Sixteenth and Sycamore Streets, plans installation of power equipment in new addition to meat-packing plant, 100x120 ft. Entire project will cost about $100,000. H. Peter Henschien, 69 East Van Buren Street, Chicago, Ill., is engineer.

Ky., Covington—Bavarian Brewing Co., Twelfth and Pike Streets, plans installation of power equipment in connection with expansion and improvements in brewing plant. Entire project will cost close to $100,000. Leslie S. Deglow, Electric Building, Cincinnati, Ohio, is architect; Carl J. Kiefer, Schmidt Building, Cincinnati, is consulting engineer.

Ky., Latonia—Latonia Refining Co., plans installation of power equipment in connection with expansion and improvement program at local oil refining plant. New steel pipe lines will be built for crude oil service. Entire project will cost close to $400,000. Company headquarters are in Midland Bank Building, Cleveland, Ohio.

Mass., Ayer—Neshoba Cold Storage Co., Westboro, Mass., H. P. Gilmore, head, has preliminary plans for new three-story cold storage and refrigerating plant at Ayer. Proposed to begin work early next spring. Cost about $70,000, with equipment. F. J. Sill, East Main Street, Westboro, is engineer.

Mich., Battle Creek—George Weston Biscuit Co., Toronto, Ont., and 2 Brighton Avenue, Passaic, N. J., plans installation of power equipment in new branch cracker and biscuit manufacturing plant at Battle Creek. Company has acquired former local factory of Sanitarium Equipment Co., and will remodel and improve at once. Cost over $100,000, with equipment.

Mich., Benton Harbor—Benton Harbor Fruit Association plans installation of a cold storage and refrigerating plant in new five-story fruit storage and distributing building, 110x140 ft. Also will install power equipment and material-handling equipment. Entire project will cost close to $200,000. Don Lakie, Grand Rapids, Mich., is architect.

Mich., Grand Haven—City Council has plans maturing for extensions and improvements in municipal electric light and power plant, with installation of new equipment. Cost about $75,000. Hamilton & Weever, Grand Rapids, Mich., are consulting engineers.

Miss., Jackson—City Council has plans maturing for new municipal electric light and power plant, and electrical distribution system. A special election has been called on January 19 to vote bonds for $1,500,000 for project.

Miss., Pelahatchie—Pearl River Valley Lumber Co. plans rebuilding of one-story power house, recently destroyed by fire. Also will rebuild lumber mill, with installation of power equipment, destroyed at same time. Entire loss about $100,000.

Mo., Kansas City—Liquid Carbonic Co., 2000 Baltimore Avenue, plans installation of electric power equipment in new dry ice-manufacturing plant on Fourteenth Street. Entire project will cost about $250,000. Frank C. Becker is local manager. Company headquarters are at 3100 South Kedzie Avenue, Chicago, Ill.

Mo., Maryville—Imperial Brewing Co., 122 Southwest Boulevard, Kansas City, Mo., plans installation of power equipment in proposed new brewing plant at Maryville, where site is being selected. A boiler house will be built. Entire project will cost close to $85,000. E. B. Collins is general manager.

N. J., Jersey City—Colgate-Palmolive-Peet Co., 105 Hudson Street, has filed plans for new one-story steam power plant at soap and perfumery factory. Company will also install power equipment in connection with an expansion and modernization program. Entire project will cost over $400,000. J. A. Coulter is vice-president.

Ohio, Cincinnati—Proctor & Gamble Co., Gwynn Building, plans installation of electric power equipment in new two-story addition to soap manufacturing plant at Ivorydale. Cost about $60,000. Work will soon begin.

Ohio, Cleveland—Department of Utilities, City Hall, William Rogers, director, has plans maturing for new mechanical blower plant at sewage treatment works, East 140th Street and Lake Shore Boulevard. Cost over $300,000 with equipment. George B. Gascoigne & Co., Leader Building, are consulting engineers.

Pa., Homestead—Carnegie Steel Co., a subsidiary of United States Steel Corporation, 71 Broadway, New York, N. Y., plans installation of electric power equipment in two new plate mills at Homestead steel works. Entire project will cost more than $5,000,000. Company engineering department is in charge.

Pa., Pittsburgh—National Steel Corporation, Grant Building, Pittsburgh, plans installation of electric power equipment in connection with expansion and improvements at mills, including new addition to plant of subsidiary, Great Lakes Steel Corporation, Ecorse, near Detroit, Mich. Entire project will cost close to $10,000,000, and will be carried out in 1935.

Tenn., Bristol—East Tennessee Light & Power Co., State Street, plans rebuilding of portion of artificial gas plant, recently destroyed by fire, with installation of new equipment. New one-story boiler house will be built, with two fire-tube boilers, stokers, feedwater equipment and accessories. Entire project will cost over $65,000. R. I. Butterworth is general superintendent.

Tenn., Pickwick Landing—Tennessee Valley Authority, Knoxville, Tenn., has plans under way for new control dam on Tennessee River, near Pickwick Landing, designed as highest single-lock navigation dam in country. At later date, a hydroelectric generating plant will be built at dam site, with initial capacity of 204,000 kw., divided into six units each of 34,000 kw. rating. Transmission lines, power substations and switching stations will be built. Entire project is estimated to cost $22,000,000. Alex M. Torpen will be construction engineer in charge.

Utah, Salt Lake City—Fisher Co., Tenth Street West, has taken out a permit for new boiler plant at brewery. Also will install power equipment in connection with expansion and improvements in brewing plant. Entire project will cost close to $40,000.

Va., Glasgow—Blue Ridge Co., Inc., care of Ballinger Co., 105 South Twelfth Street, Philadelphia, Pa., architect and engineer, plans installation of electric power equipment in new carpet and woolen mill on large tract of land purchased at Glasgow. A power house will be built. Entire project will cost over $200,000. Company was organized recently as an interest of Charles P. Cochrane Co., Kensington Avenue and Butler Street, Philadelphia, manufacturer of carpets, etc.